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# **Anton de Kom University of Suriname**

Faculty of Mathematics and Natural Sciences

Department: Chemistry

## **Assessing Mercury Levels in Surface Water and Soil: The Influence of Goldsmith and Gold Buy-up Shop Practices in Paramaribo**

A thesis submitted in partial fulfillment of the requirements for the  
Degree of Bachelor of Science in Chemistry

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Date of submission: 11<sup>th</sup> of November 2025

## Statement of Own Work

The student hereby declares that the submitted graduation work is his own.

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A handwritten signature in cursive script that reads "Bandhoe" followed by a stylized flourish consisting of several overlapping loops.

## **Abstract**

Mercury pollution is a pressing environmental and public health concern, particularly in countries where artisanal and small-scale gold processing is common. In Paramaribo, Suriname, goldsmiths and gold buy-up shops are suspected sources of localized mercury contamination. This study assessed mercury concentrations in surface water and underlying soil collected near such businesses and compared them with reference sites, unaffected by gold-processing activities. Ten water and ten soil samples were analyzed using Cold Vapor Atomic Absorption Spectrometry (CV-AAS) and Flow Injection Mercury System (FIMS) techniques. Results showed no detectable mercury in any of the water samples, regardless of proximity to gold-processing shops. In contrast, soil samples collected near gold buy-up shops exhibited significantly elevated mercury levels (mean = 122.9 ppb) compared to soils farther away (mean = 16.9 ppb). Statistical analyses, including Welch's t-test and Mann–Whitney U test, confirmed these differences as highly significant ( $p < 0.05$ ). Although concentrations were well below international intervention thresholds, localized hotspots with values up to 317 ppb were identified, indicating potential long-term environmental risks. The findings highlight the role of soils as sinks for mercury in urban environments and underscore the need for continued monitoring, policy intervention, and public health awareness to mitigate mercury exposure in Paramaribo.

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## List of Abbreviations and Acronyms

**AAS** – Atomic Absorption Spectrometry

**ASGM** – Artisanal and Small-Scale Gold Mining

**CV-AAS** – Cold Vapor Atomic Absorption Spectrometry

**CVAFS** – Cold Vapor Atomic Fluorescence Spectrometry

**DMA** – Direct Mercury Analyzer

**EPA** – Environmental Protection Agency

**FIMS** – Flow Injection Mercury System

**GPS** – Global Positioning System

**H<sub>2</sub>SO<sub>4</sub>** – Sulfuric Acid

**Hg** – Mercury

**Hg(NO<sub>3</sub>)<sub>2</sub>** – Mercury(II) Nitrate

**HNO<sub>3</sub>** – Nitric Acid

**ICP-MS** – Inductively Coupled Plasma Mass Spectrometry

**K<sub>2</sub>S<sub>2</sub>O<sub>8</sub>** – Potassium Persulfate

**KMnO<sub>4</sub>** – Potassium Permanganate

**MeHg** – Methylmercury

**NaCl** – Sodium Chloride

**NZCS** – National Zoological Collection of Suriname (NZCS Laboratory)

**ppb** – Parts per Billion

**PPE** – Personal Protection Equipment

**ppm** – Parts per Million

**SnCl<sub>2</sub>** – Stannous Chloride

**TGM** – Total Gaseous Mercury

**UNEP** – United Nations Environment Programme

**WHO** – World Health Organization

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# Chapter 1. Introduction

## 1.1. General Overview

Mercury is a heavy metal with serious consequences for both the environment and human health. It occurs in three main forms: elemental ( $\text{Hg}^0$ ), inorganic, and organic mercury—the most common being methylmercury (MeHg). Of these, MeHg is especially concerning because it does not simply remain in water but builds up in living organisms. Small aquatic species absorb it first, after which larger fish accumulate even higher levels. Ultimately, humans and other top predators face the greatest risks. This process is worsened by mercury's strong affinity for organic matter in sediments, which allows it to persist and cycle through aquatic ecosystems, making them particularly vulnerable to long-term contamination (Chen et al., 2014; Kumar et al., 2023).

Mercury pollution mainly stems from anthropogenic activities such as gold mining, coal combustion, and waste incineration. In artisanal and small-scale gold mining, for example, mercury is widely used to amalgamate gold, but large amounts escape into the surrounding soil and water (UN Environment, 2019). Once in aquatic environments, certain microorganisms can convert inorganic mercury into methylmercury, the most toxic and persistent form. This compound does not simply disperse in water; instead, it accumulates in aquatic organisms and subsequently biomagnifies through the food chain (Jeong et al., 2024; Ren et al., 2025). As a result, even relatively low concentrations of mercury in surface waters can become a major health risk for populations that rely heavily on fish consumption, with particular concern for vulnerable groups such as pregnant women and children (Cohen et al., 2005; US EPA, 2025).

Exposure to mercury—particularly in the form of methylmercury—poses significant risks to human health. Methylmercury is a potent neurotoxin that interferes with brain development and functioning, leaving fetuses and young children especially vulnerable. Even low-level prenatal exposure has been associated with reduced IQ, attention deficits, and long-term cognitive impairments (Charkiewicz et al., 2025). In adults, chronic exposure can also contribute to kidney dysfunction and suppressed immune responses (US EPA, 2025). Given these wide-ranging effects, international frameworks such as the Minamata Convention were developed to reduce global mercury emissions and safeguard both ecosystems and human health (UN Environment, 2019).

In Paramaribo, surface water and soil located near goldsmiths and gold buy-up shops are likely to contain higher mercury concentrations than those found in areas without gold-processing activities. This difference can be explained by the frequent use of mercury in these businesses, where its release and improper disposal during processing contribute to localized environmental contamination.

This study focuses on mercury contamination in surface water and soil near goldsmiths and gold buy-up shops in Paramaribo, with the goal of determining whether elevated concentrations can be traced back to gold-processing practices. Gaining insight into the way mercury behaves in water and sediments is especially important, since these dynamics shape how much of the metal becomes bioavailable—and, in turn, how strongly it accumulates in local plants and animals (Chen et al., 2014).

## 1.2. Problem Statement

In Paramaribo, the quality of surface water and soil is increasingly threatened by the activities of goldsmiths and gold buy-up shops. These businesses often rely on mercury, a toxic heavy metal widely used in artisanal gold processing. The handling and disposal of mercury during such practices can contaminate the environment, raising concerns about the safety of nearby water bodies and surrounding land (Ouboter et al., 2012).

Importantly, it is not only the water that faces risk. The soils beneath and around ditches and creeks can act as long-term sinks for mercury, gradually releasing it back into the environment and thereby endangering both ecosystems and human health. Despite these concerns, little research has been conducted to determine the extent of mercury contamination in Paramaribo's urban setting, particularly in areas surrounding goldsmiths and gold buy-up shops.

Recognizing this gap, the present study focuses on measuring mercury concentrations in both surface water and soils near these businesses and comparing them with samples from unaffected locations. By identifying whether mercury levels are elevated in these environments, this research seeks to provide scientific evidence on the extent of contamination in Paramaribo and contribute to a clearer understanding of the associated environmental and public health risks.

## 1.3. Main Research Question and Sub-questions

### Main Research Question

- To what extent are mercury concentrations in surface water and underlying soil near goldsmiths and gold buy-up shops in Paramaribo elevated compared to areas not influenced by such activities?

### Sub-Questions

1. What are the present mercury concentrations in surface water and soil samples collected near goldsmiths and gold buy-up shops in Paramaribo?
2. How do these concentrations differ from those measured in areas without gold-processing activities?
3. What environmental and public health risks may arise from the levels of mercury detected in surface water and soil near these businesses?
4. How do the measured mercury concentrations compare with international standards or guidelines for safe mercury levels in water and soil?
5. Predictive: Based on current trends, what future impacts might the continued activities of goldsmiths and gold buy-up shops have on surface water mercury levels in Paramaribo?

## 1.4. Hypothesis

**Null Hypothesis (H<sub>0</sub>):** There is no significant difference in mercury concentrations in surface water and underlying soil near goldsmiths and gold buy-up shops in Paramaribo compared to areas not influenced by gold-processing activities.

**Alternative Hypothesis (H<sub>1</sub>):** Mercury concentrations in surface water and underlying soil near goldsmiths and gold buy-up shops in Paramaribo are significantly higher than those measured in areas not influenced by gold-processing activities.

## 1.5. Relevance of this Project

### Importance of the Subject

Mercury pollution represents a serious threat to both environmental integrity and public health, particularly in regions where artisanal gold mining and processing are widespread. In Paramaribo, goldsmiths and gold buy-up shops are suspected sources of mercury releases into surface water and soil (Ouboter et al., 2012; Vreedzaam et al., 2023). Mercury is a potent neurotoxin, and exposure has been linked to neurological damage, impaired brain development, and other health effects. Vulnerable groups such as children and pregnant women face the highest risks, even at low levels of exposure (Charkiewicz et al., 2025).

Understanding how widespread mercury contamination is will be essential for developing effective strategies to reduce exposure. Such knowledge is critical not only for protecting human health but also for preserving the quality of the local environment and ensuring its resilience for future generations (UN Environment, 2019; US EPA, 2025).

### Knowledge Gaps

At present, there is limited detailed information on mercury concentrations in surface water and soil that can be directly linked to the activities of goldsmiths and gold buy-up shops in Paramaribo. Although mercury pollution has been studied in Suriname more broadly, most research has focused on artisanal and small-scale gold mining in rural areas rather than on urban sources (Gray et al., 2002; Ouboter, 2015). The specific contribution of goldsmiths and buy-up shops to local contamination of water and soil has not yet been thoroughly investigated. This study aims to address this gap by systematically measuring mercury levels in different locations and examining their potential connection to gold-processing activities in the city (Vreedzaam et al., 2023).

### Expected Insights

This research is expected to make several important contributions:

1. **Quantitative data** – It will provide clear measurements of mercury concentrations in surface water and soil near goldsmiths and gold buy-up shops, compared with samples from areas not influenced by these activities.
2. **Correlation analysis** – It will offer evidence of how mercury levels may be connected to gold-processing practices, giving a more precise picture of their environmental impact.

3. **Risk assessment** – It will contribute to an understanding of the potential environmental and public health risks posed by mercury pollution in Paramaribo, supporting health and safety considerations.
4. **Basis for action** – It will establish a foundation of information that can guide future research, as well as policy and regulatory measures aimed at reducing mercury pollution and protecting both communities and ecosystems.

By addressing these points, the study not only fills an important knowledge gap but also generates practical insights that are both socially relevant and academically valuable.

## 1.6. Thesis Outline

This thesis is organized into six main chapters.

- **Chapter 1 – Introduction**

This chapter provides the general background of mercury as an environmental contaminant, highlighting its forms, pathways, and associated health risks. It also introduces the problem context in Paramaribo, where goldsmiths and gold buy-up shops are potential sources of mercury pollution. The research problem, objectives, research questions, and significance of the study are clearly defined.

- **Chapter 2 – Literature Review**

The literature review explores existing knowledge on mercury pollution, including its global and regional sources, behavior in aquatic and terrestrial environments, and health impacts. It also reviews previous studies conducted in Suriname and comparable contexts, as well as common analytical methods used for mercury detection in water and soil. This chapter establishes the scientific basis and identifies the knowledge gap addressed by the present research.

- **Chapter 3 – Methodology**

This chapter describes the study design, including the sampling strategy, sample collection procedures for surface water and soil, and laboratory analysis techniques. It outlines the instruments used (CV-AAS, FIMS), quality control measures, and the statistical methods employed to evaluate the data.

- **Chapter 4 – Results and Discussion**

This chapter presents the findings of the study, beginning with mercury concentrations in surface water and soil, followed by statistical analyses comparing impacted and control sites. The discussion interprets these results in light of international guidelines, previous studies, and potential health and environmental implications. The research questions are addressed directly, and the broader significance of the findings is highlighted.

- **Chapter 5 – Conclusions**

This chapter provides a concise summary of the main conclusions drawn from the research. It highlights the answers to the research questions and emphasizes the overall contribution of the study to understanding mercury contamination in Paramaribo.

- **Chapter 6 – Recommendations**

The final chapter offers recommendations for policymakers, local communities, and researchers. It emphasizes the importance of preventive measures, improved regulation, awareness programs, and long-term monitoring. It also points to future research directions to deepen the understanding of mercury pollution in urban environments.

## Chapter 2. Literature Review

### 2.1. Origins of Mercury Pollution

Mercury pollution arises from both natural processes and human activities, with the latter accounting for the majority of emissions worldwide (Pacyna et al., 2010). Key anthropogenic sources include the following:

- **Coal combustion.** Coal burning is one of the largest contributors to global mercury emissions. Pacyna et al. (2010) estimated that coal combustion accounts for nearly 50% of total anthropogenic mercury emissions. Coal-fired power plants release mercury into the atmosphere, where it can travel long distances before being deposited onto land and water surfaces (Pacyna et al., 2010).
- **Industrial activities.** In addition to coal combustion, other industrial processes such as cement production and waste incineration also release significant amounts of mercury into the environment. These emissions contribute to elevated mercury levels, compounding the global pollution burden (UN Environment, 2019).
- **Artisanal and small-scale gold mining (ASGM).** ASGM is another major source, responsible for approximately 37% of global mercury emissions. In this process, mercury is used to amalgamate gold, but much of it is lost to the environment. Once released into soils and waterways, mercury can be transformed into methylmercury, a highly toxic form that bioaccumulates in aquatic organisms and ultimately threatens both ecosystems and human health (Esdaile & Chalker, 2018).

### 2.2. Atmospheric Transport and Deposition

Mercury released into the atmosphere has a relatively long lifetime, estimated at around six months (Bich Thao et al., 2021). During this time, it can be transported across vast distances before eventually depositing onto land or water surfaces, contributing to global contamination. Because of this ability to travel, atmospheric mercury does not remain confined to its source regions; instead, it can cross continents and reach even remote and sensitive areas such as the Arctic, where it poses risks to fragile ecosystems and communities.

### 2.3. Global and Regional Contributions

According to the United Nations Environment Programme (UNEP), global mercury emissions are estimated at around 2,000 metric tons per year (UN Environment, 2019). The largest contributors are countries in Asia, particularly China and India, where extensive coal combustion and artisanal or small-scale gold mining remain major sources of mercury release.

Once emitted, mercury does not remain confined to its original source. It can enter oceans, soils, and the atmosphere, traveling great distances before settling. This global distribution results in widespread mercury accumulation in fish and wildlife, posing significant risks to human populations that depend on aquatic resources for protein (UN Environment, 2019).

At the regional level, South America is a recognized hotspot for mercury pollution due to widespread artisanal and small-scale gold mining. In the Guianas, including Suriname, gold

mining is the largest single source of mercury emissions. Studies have documented elevated mercury concentrations in fish, sediments, and human populations living near mining areas (Gray et al., 2002; Ouboter et al., 2012; Vreedzaam et al., 2023). Importantly, evidence suggests that mercury pollution is not limited to remote mining districts but also occurs in urban centers such as Paramaribo, where goldsmiths and gold buy-up shops may act as localized sources of contamination (Ouboter et al., 2012).

## **2.4. Environmental Impact**

Mercury contamination affects multiple environmental compartments, including soil, water, and living organisms. In aquatic systems, mercury can be transformed into methylmercury, a highly toxic form that accumulates in fish and other wildlife, with serious implications for food safety and ecosystem health (Chen et al., 2014). Wetlands and other aquatic environments also play a critical role in the mercury cycle. Depending on local conditions and human activities, these systems may act either as sinks, storing mercury in sediments, or as sources that release it back into the environment (Schroeder & Munthes, 1998).

## **2.5. Health Risks Associated with Mercury Exposure**

### **2.5.1. Neurological Impacts**

Mercury, especially in its methylated form, poses serious health risks, with some of the most severe effects occurring in the nervous system:

- **Neurological impairments.** Methylmercury exposure is well documented to cause neurological damage. Research has shown that it can lead to cognitive deficits, motor dysfunction, and other impairments by disrupting brain regions involved in cognitive processing and motor coordination (Clarkson & Magos, 2006).
- **Vulnerability of the developing brain.** The developing brain is particularly susceptible to methylmercury. Prenatal exposure has been associated with developmental delays, learning disabilities, and long-term cognitive and behavioral effects in children (Gilbert & Grant-Webster, 1995).
- **Adult neurodegenerative diseases.** Chronic mercury exposure in adults has been linked to tremors, memory loss, and an increased risk of neurodegenerative diseases such as Parkinson's and Alzheimer's. Evidence suggests that mercury can exacerbate these conditions, contributing to progressive neurological decline (Charkiewicz et al., 2025).

### **2.5.2. Cardiovascular and Renal Impacts**

Mercury exposure is not only neurotoxic but also has significant effects on other organ systems, particularly the cardiovascular and renal systems:

- **Cardiovascular health.** Chronic exposure to mercury has been associated with adverse cardiovascular outcomes. Studies have linked mercury to increased risks of hypertension and heart disease, suggesting that its toxic effects on vascular and cardiac tissues may

contribute to higher rates of cardiovascular morbidity and related complications (Hu et al., 2021).

- **Renal damage.** Mercury is also known to exert nephrotoxic effects. Prolonged exposure to inorganic mercury compounds can lead to kidney damage and gastrointestinal disturbances. Accumulation of mercury in renal tissues may impair kidney function and, over time, compromise overall health (Basu et al., 2014).

### **2.5.3. Respiratory Problems**

Exposure to elemental mercury vapors can also result in respiratory complications. Occupational studies have documented symptoms such as chronic cough, shortness of breath, and other pulmonary conditions among workers exposed to mercury vapors (Park & Zheng, 2012). Inhalation of mercury irritates the respiratory tract and, with long-term exposure, may contribute to persistent respiratory health problems (Lim et al., 1998).

## **2.6. Mercury Research in Suriname**

Suriname, like many other countries with extensive gold mining activities, faces serious challenges related to mercury pollution. Early research by Mol et al. (2001) reported elevated mercury concentrations in rivers and fish near artisanal gold mining sites, underscoring the environmental impact of using mercury to amalgamate gold. These findings revealed how mercury released during processing enters aquatic systems and bioaccumulates in local food webs (Mol et al., 2001).

Subsequent studies have continued to document the scope of the problem. Ouboter (2015) provided a comprehensive review of mercury pollution in Suriname, noting high mercury concentrations not only in mining areas but also in fish sold on urban markets. The study highlighted that mercury exposure is not restricted to mining communities but also affects city dwellers through fish consumption (Ouboter et al., 2012).

More recently, Vreedzaam et al. (2023) analyzed mercury contamination across different sites in Suriname, contrasting heavily impacted mining areas with relatively pristine environments. Their findings confirmed that mercury levels in fish from mining-impacted rivers often exceeded international health guidelines, raising concerns about long-term ecological and human health impacts (Vreedzaam et al., 2023).

Together, these studies illustrate the pervasive nature of mercury contamination in Suriname and the urgent need for stronger management strategies, both at the regulatory and technological levels.

### **2.6.1. Health Impact Studies**

Research on the health impacts of mercury exposure in Suriname has revealed significant risks for local communities. De Kom et al. (2020) reported elevated mercury concentrations in blood samples taken from gold miners and their families, which were associated with neurological symptoms. These findings underscore the urgent need for targeted health interventions and routine monitoring to mitigate the effects of mercury exposure (M de Kom et al., 1998).

Complementing this, Mol et al. (2001) examined mercury levels in fish from Surinamese rivers and found that many species contained concentrations above the World Health Organization's guideline of 0.5 ppm. Since fish are a major source of protein in Suriname, this poses considerable health risks to communities that depend heavily on riverine fish for their diet (Mol et al., 2001).

## **2.7. Mercury Contamination in Suriname**

### **2.7.1. Hotspots of Contamination**

Mercury contamination in Suriname is most pronounced in gold mining areas, especially in the interior regions where artisanal and small-scale mining is widespread. Ouboter et al. (2012) documented significant mercury levels in the Marowijne and Tapanahoni rivers, which were high enough to affect fish populations and, by extension, the communities that rely on them for food. These findings align with the broader understanding that mercury released during gold processing readily disperses through aquatic systems and accumulates in the food web (Ouboter et al., 2012).

In addition to rural hotspots, studies have revealed serious urban contamination. Wip et al. (2013) reported that background levels of total gaseous mercury (TGM) in Suriname averaged around 1.4 ng/m<sup>3</sup>, consistent with global baseline values. However, in Paramaribo, where gold buy-up shops are concentrated, TGM levels were markedly higher. Measurements in surrounding air reached 109.4 ng/m<sup>3</sup>, while concentrations inside the shops were as high as 60,000 ng/m<sup>3</sup>—posing severe health risks for workers and nearby residents (Wip et al., 2013).

When compared internationally, Paramaribo's per capita mercury emissions were found to be significantly higher than those of larger cities such as Changchun, China, and the city also experienced more intense and prolonged pollution spikes than New York City (Wip et al., 2013). The study attributed these emissions primarily to gold buy-up shops, where mercury is burned off during gold purification, though industrial sources such as alumina refining may also play a role. The authors concluded that while ambient urban mercury levels in Paramaribo are within the global range, occupational and localized exposures in and around buy-up shops represent a serious public health concern. They recommended further investigation into industrial contributions as well as stricter controls to reduce health risks (Wip et al., 2013).

### **2.7.2. Regulatory and Remediation Efforts**

Efforts to address mercury pollution in Suriname have so far been limited. International assessments, such as those by the United Nations Environment Programme (UN Environment, 2019), have stressed the importance of introducing mercury-free mining technologies and strengthening environmental regulations in countries where artisanal and small-scale gold mining

is widespread. Ouboter similarly highlighted Suriname's lack of effective regulatory frameworks to control mercury use and called for more robust policies and technologies to reduce reliance on this toxic metal (Ouboter et al., 2012). Recent studies also emphasize that international cooperation and financial support are essential to facilitate the transition toward cleaner mining practices (UN Environment, 2019; Vreedzaam et al., 2023).

## **2.8. Analysis of Mercury in Water and Soil**

### **2.8.1. Analytical Methods for Water**

For water analysis, mercury is measured as total mercury, methylmercury, and inorganic mercury, respectively. O'Dell et al discusses various techniques, including cold vapor atomic absorption spectrometry (CV-AAS) and inductively coupled plasma mass spectrometry (ICP-MS). These methods are ideal for detecting low concentrations of mercury in aquatic systems (O'Dell et al., 1994).

Louie et al. (2012) emphasizes the importance of sample preservation and contamination control in water analysis. Advanced methods like high-resolution ICP-MS offer improved detection limits and the ability to analyse multiple mercury species simultaneously (Louie et al., 2012).

### **2.8.2. Analytical Methods for Soil**

When studying mercury in soil, the focus is usually on measuring total mercury levels and, in some cases, identifying specific forms such as methylmercury. A common approach is to use cold vapor atomic absorption spectrometry (CV-AAS) or cold vapor atomic fluorescence spectrometry (CVAFS) after acid digestion of soil samples. These methods have long been valued for their reliability in detecting total mercury (Gray et al., 2015).

In recent years, newer techniques have made the process faster and simpler. The Direct Mercury Analyzer (DMA), for example, uses thermal decomposition and amalgamation with atomic absorption detection to measure mercury directly in solid samples, eliminating the need for wet chemical digestion (Milestone Science, n.d.). Another method that has gained popularity is inductively coupled plasma mass spectrometry (ICP-MS), which offers high sensitivity and also allows researchers to measure multiple elements in a single run (Han et al., 2006).

## Chapter 3. Materials and Methods

### 3.1. Materials and Equipment

- Sampling containers:
  - Type: Clean, acid-washed polypropylene bottles.
  - Quantity: 10 bottles (5 for samples near goldsmiths and buy-up shops, 5 for control samples).
  - Type: clean, acid-washed zip lock bags.
  - Quantity: 7
- Preservatives:
  - Type: Concentrated nitric acid ( $\text{HNO}_3$ ) for preserving water samples.
  - Quantity: 0.5 mL per sampling bottle.
- Atomic Absorption Spectrometer (AAS):
  - Type: AAS equipped with cold vapor atomic absorption capabilities.
  - NZCS lab: Bacharach Coleman Model 50D Mercury Analyzer System.
  - Filab: Flow Injected Mercury System.
- Mercury standards:
  - Type: AAS grade mercury standard.
- Laboratory glassware:
  - Type: Beakers, pipettes, and volumetric flasks.
  - Quantity: Standard laboratory set (at least 5 of each type).
- Safety equipment:
  - Type: Personal protective equipment (PPE) such as gloves, lab coats, and safety goggles.
  - Quantity: Sufficient for all personnel involved in the sampling and analysis.
- Field equipment:
  - Type: Smartphone GPS for accurate location tracking.
  - Quantity: 1 smartphone GPS device.
- Data analysis software:
  - Type: Python
  - Quantity: 1 license or access to software.
- Documentation supplies:
  - Type: Notebooks, recording sheets, and data loggers for field data.
  - Quantity: Sufficient for recording all sample details and observations.
- Cleaning supplies:
  - Type: Detergents, deionized water, and cleaning brushes for cleaning glassware.
  - Quantity: As needed for laboratory use.

### 3.2. Chemicals and Quantities

- Nitric acid ( $\text{HNO}_3$ ):
  - Concentrated nitric acid, J.T. Baker Analyzed ACS reagent
  - Quantity: Approximately 100 mL. This is used for sample digestion if needed for pre-treatment or preparation.

- 5% nitric acid
  - Quantity: 100 mL
- Mercury standards:
  - 1 g/L mercury standard, Inorganic Ventures
  - Quantity: 1 mL to prepare mercury standards
- Distilled water:
  - Type: High purity distilled water.
  - Quantity: At least 5 liters. Used for cleaning glassware, preparing solutions, and diluting standards.
- Potassium permanganate (KMnO<sub>4</sub>):
  - 5% potassium permanganate solution
  - Quantity: 100 mL
- Potassium persulfate (K<sub>2</sub>S<sub>2</sub>O<sub>8</sub>):
  - 5% potassium persulfate solution
  - Quantity: 100 mL
- Sodium chloride (NaCl):
  - Quantity: 12 grams
- Hydroxylamine hydrochloride:
  - Quantity: 12 grams
- Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>):
  - 0.5 N sulfuric acid
  - Quantity: 100 mL
- Stannous chloride (SnCl<sub>2</sub>):
  - 10% stannous chloride solution with 0.5 N sulfuric acid
  - Quantity: 100 mL

### **3.3. Methodology**

#### **3.3.1. Research Design and Sampling Location**

This research employs a comparative and quantitative approach to assess mercury concentrations in surface water and soil underneath from locations near goldsmiths and gold buy-up shops compared to non-influenced areas. The sample locations are divided into two groups:

- The first is “*far*”, where the distance between the sampling point and gold buy-up shops is greater than 250 meters, and where the sampling point is outside the direct wind or current path.
- The second is “*close*” where the distance between the sampling point and gold buy-up shops is less than 250 meters and within the direct wind or current path.

See sampling locations and coordinates in Table 1 and in Figure 1-3.

*Table 1. Overview of samples and details of the samples*

<b>Sample number</b>	<b>Sampling type</b>	<b>Sampling location</b>	<b>Sampling coordinates</b>	<b>Distance from gold buy-up shops</b>	<b>Closest gold buy-up shop</b>
<b>1</b>	Water	Gutter at Copernicusstreet	5.8468669, - 55.1402799	Close	100 meters
<b>2</b>	Water + soil	Gutter at Copernicusstreet	5.8548193, - 55.1569130	Close	30 meters
<b>3</b>	Water + soil	Gutter at Rubensstreet	5.8519006, - 55.1573315	Far	300 meters
<b>4</b>	Water + soil	Gutter at Jan Steenstreet	5.8495852, - 55.1445805	Close	100 meters
<b>5</b>	Water + soil	Gutter at Jamaludinstreet	5.8384455, - 55.1457433	Close	20 meters
<b>6</b>	Water + soil	Gutter at Copernicusstreet	5.8481867, - 55.1426456	Close	150 meters
<b>7</b>	Water + soil	Gutter at Maikoestreet	5.8498730, - 55.1554143	Far	540 meters
<b>8</b>	Water + soil	Gutter at Kristalstreet	5.8498667, - 55.1343147	Far	650 meters
<b>9</b>	Water	Gutter at Wolframstreet	5.8654427, - 55.1455458	Far	1650 meters
<b>10</b>	Water	Gutter at Ketelstreet	5.8796025, - 55.1482146	Far	2930 meters
<b>A</b>	Soil	Gutter at Copernicusstreet	5.8486111, - 55.1433333	Close	200 meters
<b>B</b>	Soil	Gutter at Copernicusstreet	5.8491667, - 55.1438888	Close	160 meters
<b>C</b>	Soil	Gutter at Copernicusstreet	5.8497222, - 55.1449999	Close	60 meters

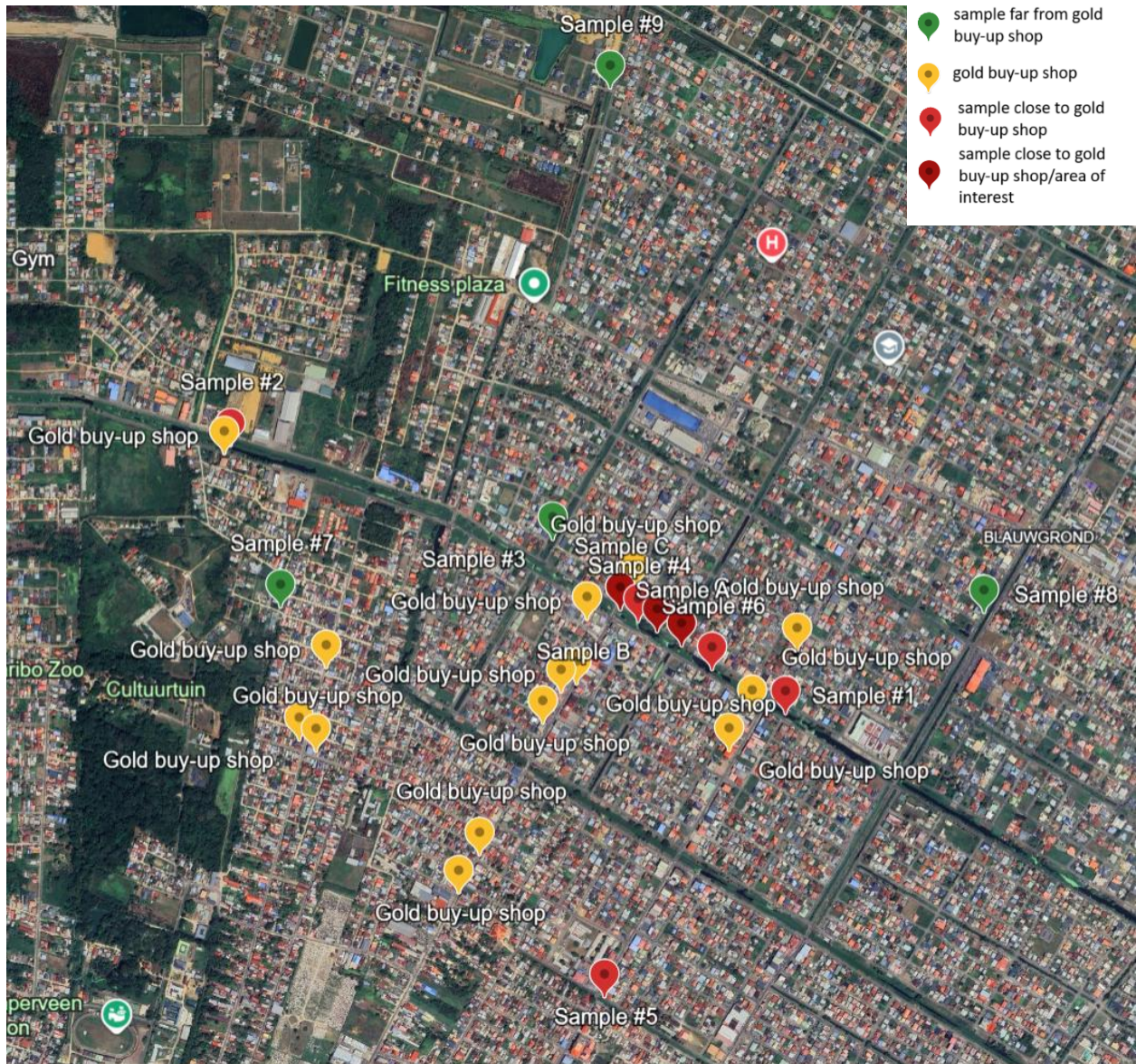


Figure 1. Satellite image of the sampling sites and gold buy-up shops



Figure 2. Google Maps image of the sampling sites and gold buy-up shops

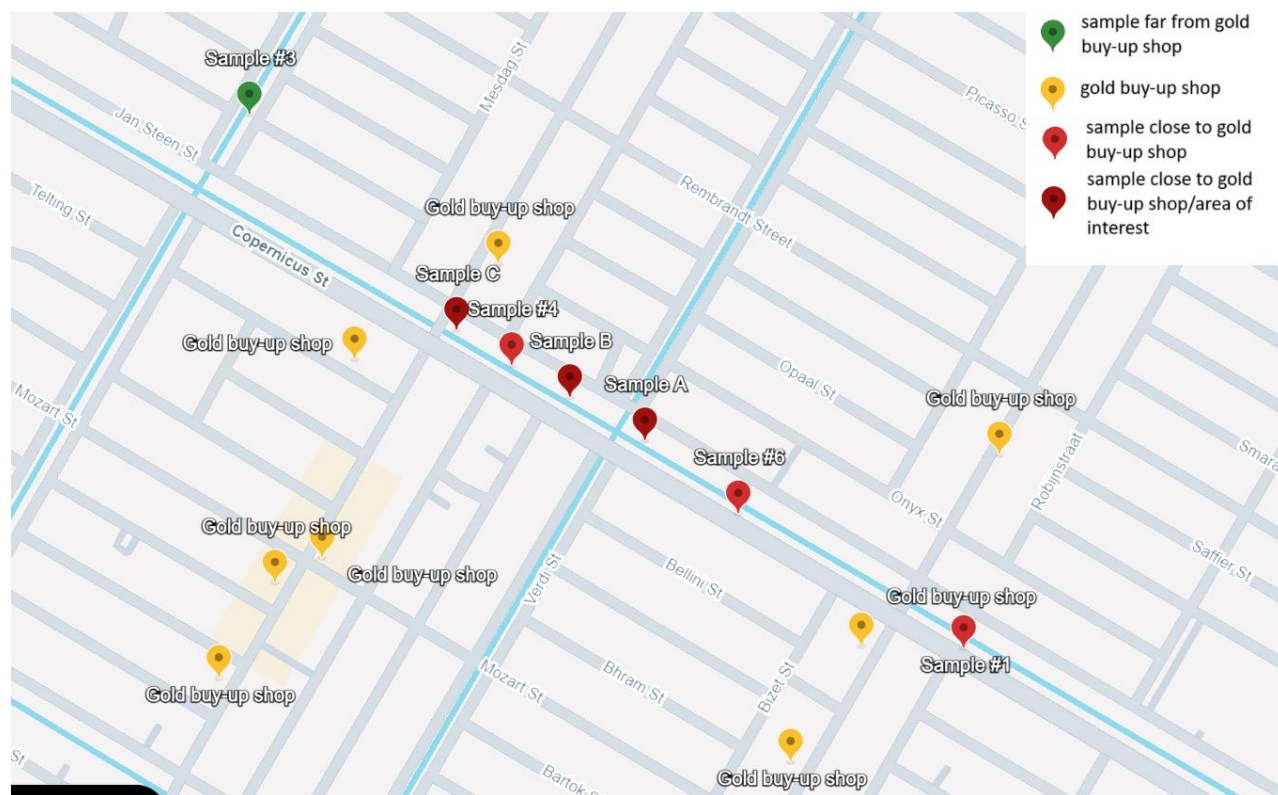


Figure 3. Satellite image of the sampling sites and gold buy-up shops around area of interest (high mercury)

### 3.3.2. Sample Collection

#### Surface Water Samples

Surface water samples were collected in 250 mL polypropylene bottles. Before use, all bottles were carefully cleaned with deionized water and rinsed with dilute nitric acid to minimize the risk of contamination. To preserve the integrity of the samples, 0.5 mL of concentrated nitric acid was added to each bottle using a micropipette. Approximately 250 mL of surface water was then collected per sample with a clean sampling device. Each bottle was clearly labeled and immediately placed in a cool box filled with ice. Samples remained stored in the cool box overnight and were transported to the laboratory the following day for analysis.

#### Soil Samples

Soil samples were collected in 2 L plastic zip-lock bags. Prior to sampling, the bags were rinsed with deionized water and dilute nitric acid to reduce the risk of contamination. For each site, approximately 2–3 kg of soil was collected using a clean sampling device, with care taken to minimize cross-contamination between samples. Samples were taken from the top layer of the soil, at a depth of no more than 6 cm. Each bag was clearly labeled and immediately placed in a cool box filled with ice. As with the water samples, the soil samples were stored overnight in the cool box and transported to the laboratory the following day for analysis.

### **3.3.3. Analytical Method**

#### **Surface Water Samples NZCS lab**

According to U.S. EPA Method 245.1, clean glass bottles were used throughout the experiment (O'Dell et al., 1994). Calibration standards of 0.5, 1, 2, 5, and 10 ppb were prepared by serial dilution of a 1 g/L mercury stock solution (mercury(II) nitrate,  $\text{Hg}(\text{NO}_3)_2$ ) with distilled water. A blank solution consisting of distilled water was also prepared.

For each calibration standard and the blank, 100 mL of solution was transferred into clean glass bottles. To each bottle, 5 mL of concentrated sulfuric acid and 2.5 mL of concentrated nitric acid were added, followed by 15 mL of a 5% potassium permanganate solution to oxidize all mercury species to  $\text{Hg}^{2+}$ . The bottles were left at room temperature for 15 minutes, after which 8 mL of a 5% potassium persulfate solution was added to ensure complete digestion. The bottles were then placed in a water bath at 95 °C for two hours.

Water samples were prepared using the same procedure. For each sample, 100 mL was transferred into two clean glass bottles, treated with sulfuric and nitric acids, potassium permanganate, and potassium persulfate, and digested in a 95 °C water bath for two hours. After digestion, the bottles were cooled in an ice bath. Excess oxidizing agents were neutralized with a sodium chloride–hydroxylamine hydrochloride solution. Mercury ions ( $\text{Hg}^{2+}$ ) were then reduced to elemental mercury ( $\text{Hg}^0$ ) using a freshly prepared 10% stannous chloride ( $\text{SnCl}_2$ ) solution.

The elemental mercury vapor generated was measured by cold vapor atomic absorption spectrometry (CV-AAS) at a wavelength of 253.7 nm. All analyses were performed in accordance with standard laboratory procedures, and results were processed using the instrument's software.

#### **Surface Water Samples Filab Suriname NV**

The mercury concentration in surface water samples was determined at Filab Suriname N.V. using a Flow Injection Mercury System (FIMS) coupled with Cold Vapor Atomic Absorption Spectrometry (CV-AAS). Due to company privacy policies, it was not possible to be present during the analytical procedures; therefore, the description below is based on general standard protocols for FIMS analysis and information provided by the laboratory.

Prior to analysis, water samples were acidified with concentrated nitric acid and stored under cooled conditions to preserve mercury stability. Before measurement, the samples were digested with an oxidizing mixture, typically potassium permanganate and potassium persulfate, to convert all mercury species to inorganic mercury ( $\text{Hg}^{2+}$ ). Excess oxidizing agents were subsequently neutralized with hydroxylamine hydrochloride.

The FIMS automated the steps of sample introduction, reduction, and detection. In this system, mercury ions were chemically reduced to elemental mercury ( $\text{Hg}^0$ ) vapor using a stannous chloride ( $\text{SnCl}_2$ ) solution as the reducing agent. The vapor was then separated from the liquid in a gas–liquid separator and carried by an inert gas (argon or nitrogen) into the absorption cell.

Detection was performed at 253.7 nm, corresponding to the resonance absorption line of mercury. A multi-point calibration curve was established using blank samples and calibration standards at 5, 10, 15, and 20 ppb. Quality control procedures, including blanks, duplicate analyses, and

certified reference materials, were applied to ensure accuracy and precision (O'Dell et al., 1994). All measurements were processed and evaluated using the instrument's software associated with the FIMS system.

### **Soil Samples Filab Suriname NV**

The mercury concentration in soil samples was determined at Filab Suriname N.V. using a Flow Injection Mercury System (FIMS) coupled with Cold Vapor Atomic Absorption Spectrometry (CV-AAS). Due to company privacy policies, it was not possible to be present during the analytical procedures; therefore, the description below is based on standard procedures for FIMS analysis of solid samples and information provided by the laboratory.

Prior to analysis, soil samples were homogenized and dried to remove moisture content. For digestion, 5 g of dried soil was accurately weighed into clean digestion vessels. Concentrated sulfuric acid and concentrated nitric acid were added to each sub-sample to break down organic material and release mercury. A 5% potassium permanganate solution was then introduced to oxidize all mercury species to inorganic mercury ( $\text{Hg}^{2+}$ ).

The digestion process was carried out in a water bath at approximately 95 °C for two hours. After digestion, the samples were cooled, and excess oxidizing agents were neutralized with a sodium chloride–hydroxylamine hydrochloride solution.

Following neutralization, mercury ions ( $\text{Hg}^{2+}$ ) were chemically reduced to elemental mercury ( $\text{Hg}^0$ ) using a 10% stannous chloride ( $\text{SnCl}_2$ ) solution. The generated vapor was separated from the liquid in a gas–liquid separator and transported by an inert carrier gas (argon or nitrogen) into the atomic absorption spectrometer.

Detection was performed at 253.7 nm, corresponding to the primary resonance line of mercury. Calibration was achieved through a multi-point calibration curve using blank samples and mercury standards at concentrations of 1, 2, 5, and 10 ppb. Quality control measures—including blanks, duplicate analyses, and certified reference materials—were applied to ensure accuracy and precision (US-EPA, 2007). All data were processed and evaluated using the FIMS system's dedicated software.

### **3.4. Data Analysis**

To evaluate the data collected in this study, a combination of descriptive and inferential statistical methods was applied. The first step was to calculate descriptive statistics—including mean, standard deviation, and range—for the two groups of interest: soil samples collected close to gold buy-up shops (<250 m) and those collected farther away (>250 m). This provided an overview of the central tendency and variability in mercury concentrations.

Before comparing groups, the Shapiro–Wilk test was used to check whether the data followed a normal distribution. This step is important because many statistical tests, such as the t-test, assume normally distributed data. Although the sample size for the “far” group was small, testing for normality helped guide the choice of appropriate methods.

To determine whether mercury concentrations differed significantly between groups, two complementary approaches were taken. An independent-samples t-test was conducted to compare the means of the “close” and “far” groups, under the assumption of unequal variances. The t-test is a standard method for testing whether two groups differ significantly in their averages.

Because of the relatively small sample size, and to avoid relying solely on parametric assumptions, a Mann–Whitney U test was also applied. This non-parametric test does not assume normality and compares the distributions of two groups rather than their means. Using both tests ensured that the conclusions would be reliable even if the data deviated from strict parametric assumptions.

All analyses were performed with a significance threshold of  $\alpha = 0.05$ . Results with p-values below this threshold were interpreted as statistically significant. To complement the statistical tests, boxplots and scatter plots were produced to visually illustrate differences between groups and to highlight site-specific variations, such as the elevated concentrations observed near site 4.

All statistical calculations and graphical representations were performed using Microsoft Excel and Python.

## Chapter 4. Results

### 4.1 Mercury Concentrations in Water Samples

Ten water samples were collected and analyzed for total mercury concentrations (in parts per billion, ppb). Samples 1, 2, 4, 5 and 6 were taken from areas close to gold buy-up shops, while samples 3, 7, 8, 9 and 10 were collected from areas far from such shops. The samples were analyzed by two different labs, the NZCS lab at the Anton de Kom University of Suriname and Filab Suriname NV. The results are presented in Table 2.

*Table 2. Mercury concentrations (ppb) in water samples*

<b>Sample number</b>	<b>Distance from gold buy-up shops</b>	<b>NZCS Lab result</b>	<b>Filab result</b>
<b>1</b>	Close	0 ppb	0 ppb
<b>2</b>	Close	0 ppb	0 ppb
<b>3</b>	Far	0 ppb	0 ppb
<b>4</b>	Close	0 ppb	0 ppb
<b>5</b>	Close	0 ppb	0 ppb
<b>6</b>	Close	0 ppb	0 ppb
<b>7</b>	Far	0 ppb	0 ppb
<b>8</b>	Far	0 ppb	0 ppb
<b>9</b>	Far	0 ppb	0 ppb
<b>10</b>	Far	0 ppb	0 ppb

A total of ten surface water samples were collected from creeks and ditches in northern Paramaribo, with half of the sites located within 250 meters of gold buy-up shops (classified as “close”) and the other half more than 250 meters away (classified as “far”). All surface water samples were analyzed by two independent laboratories (NZCS Laboratory at Anton de Kom University of Suriname and Filab Suriname N.V.). Both laboratories consistently reported no detectable mercury concentrations in the water samples. These results suggest that, at the time of sampling, surface water in both impacted and control areas did not contain measurable levels of mercury.

## 4.2 Mercury Concentrations in Soil Samples

Initially seven soil samples were collected and analyzed for total mercury concentrations (in parts per billion, ppb). Samples 2, 4, 5, and 6 were taken from areas close to gold buy-up shops, while samples 3, 7 and 8 were collected from areas far from such shops. The individual concentrations are presented in Table 3 and Figure 4. After the seven initial samples, another three samples were taken in the area of interest, where the mercury concentration was the highest. Every sample was taken in triplicate, the results of which are also presented in Table 3 and Figure 5 as samples A, B and C.

*Table 3. Mercury concentrations (ppb) in soil samples and Dutch and Canadian concentration guidelines for Hg in soil*

Sample number	Distance from gold buy-up shops	Filab result (ppb)	Dutch and Canadian concentration guidelines for Hg in soil (ppb)
<b>2</b>	Close	15.06	6,600 – 6,700
<b>3</b>	Far	20.26	
<b>4</b>	Close	192.73	
<b>5</b>	Close	38.57	
<b>6</b>	Close	92.34	
<b>7</b>	Far	12.08	
<b>8</b>	Far	18.31	
<b>A</b>	Close	61.82 103.22 60.33	
<b>B</b>	Close	80.15 79.24 106.98	
<b>C</b>	Close	275.38 317.49 174.50	

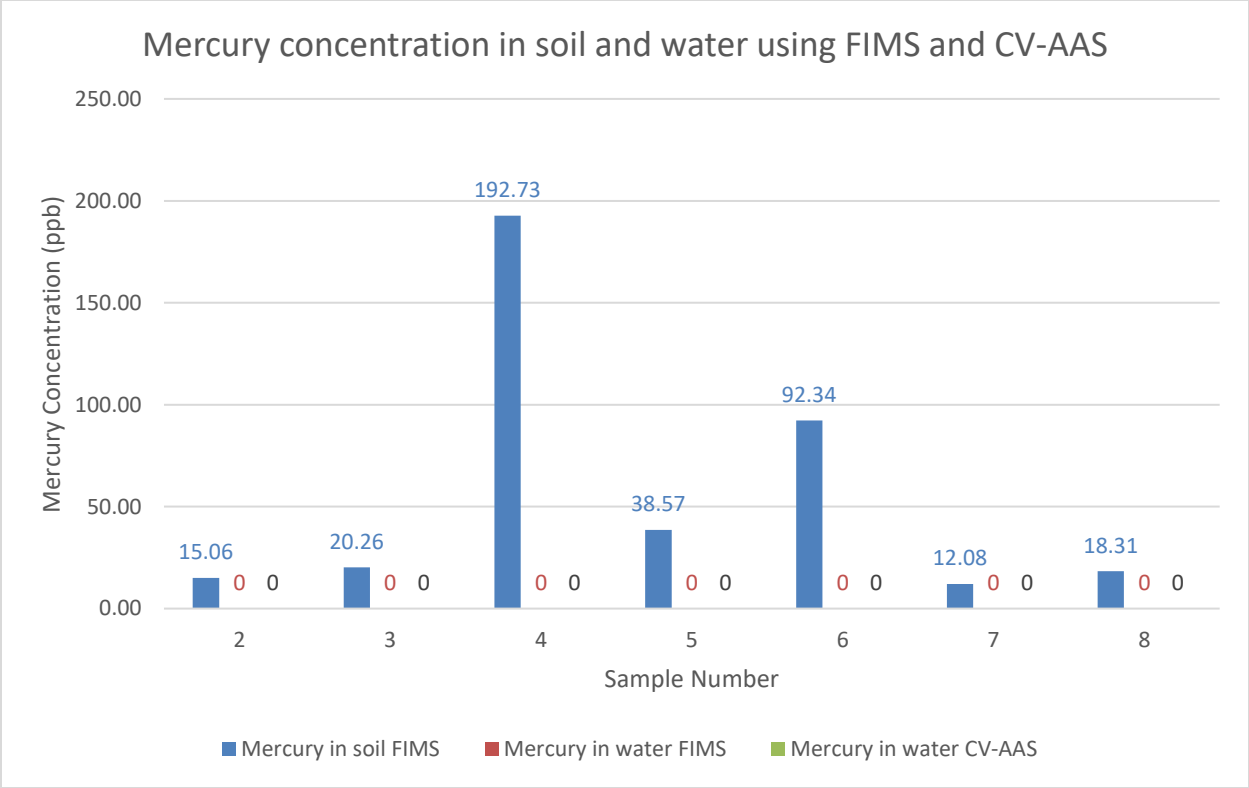


Figure 4. Graph of mercury concentrations in soil and water using FIMS (Filab) and CV-AAS (NZCS)

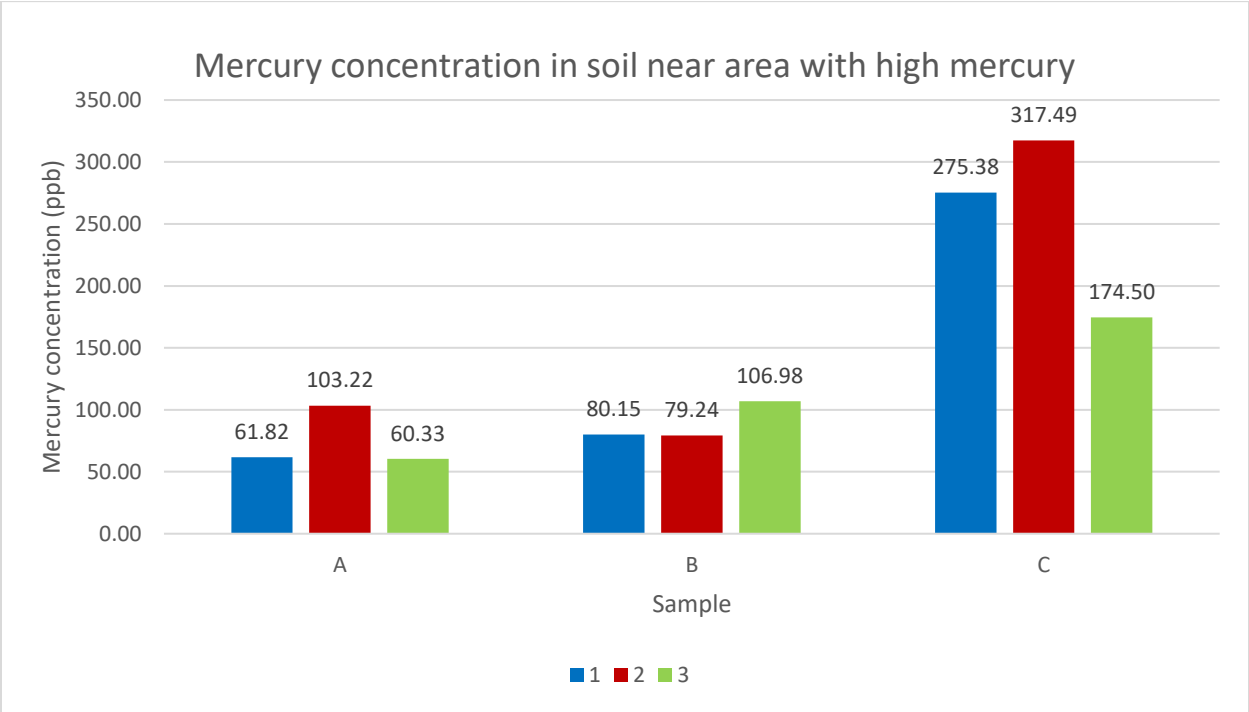


Figure 5. Chart of mercury concentrations in soil at the area of interest using FIMS (Filab)

Because mercury is known to accumulate in sediments and soils, follow-up sampling was conducted on the soil directly beneath seven of the previously tested water sites. Of these, four sites were classified as close to gold buy-up shops (samples 2, 4, 5, and 6), while three were located farther away (samples 3, 7, and 8). Mercury concentrations in soil varied widely across the locations, ranging from 12.08 ppb (sample 7, far) to 192.73 ppb (sample 4, close).

The highest initial value was observed at sample site 4, which measured 192.73 ppb, considerably higher than other sites. This prompted additional sampling in the vicinity of site 4 to better characterize the contamination. Three additional locations (A, B, and C) were sampled in triplicate. Concentrations at these sites further confirmed elevated mercury levels, particularly at site C, where values reached 317.49 ppb.

### **4.3 Statistical Analysis**

#### **Descriptive Statistics**

- Close to gold buy-up shops (n=13)
  - Mean = 122.9 ppb
  - Standard deviation = 91.4 ppb
  - Range = 15.06 – 317.49 ppb
- Far from gold buy-up shops (n=3)
  - Mean = 16.9 ppb
  - Standard deviation = 4.3 ppb
  - Range = 12.08 – 20.26 ppb

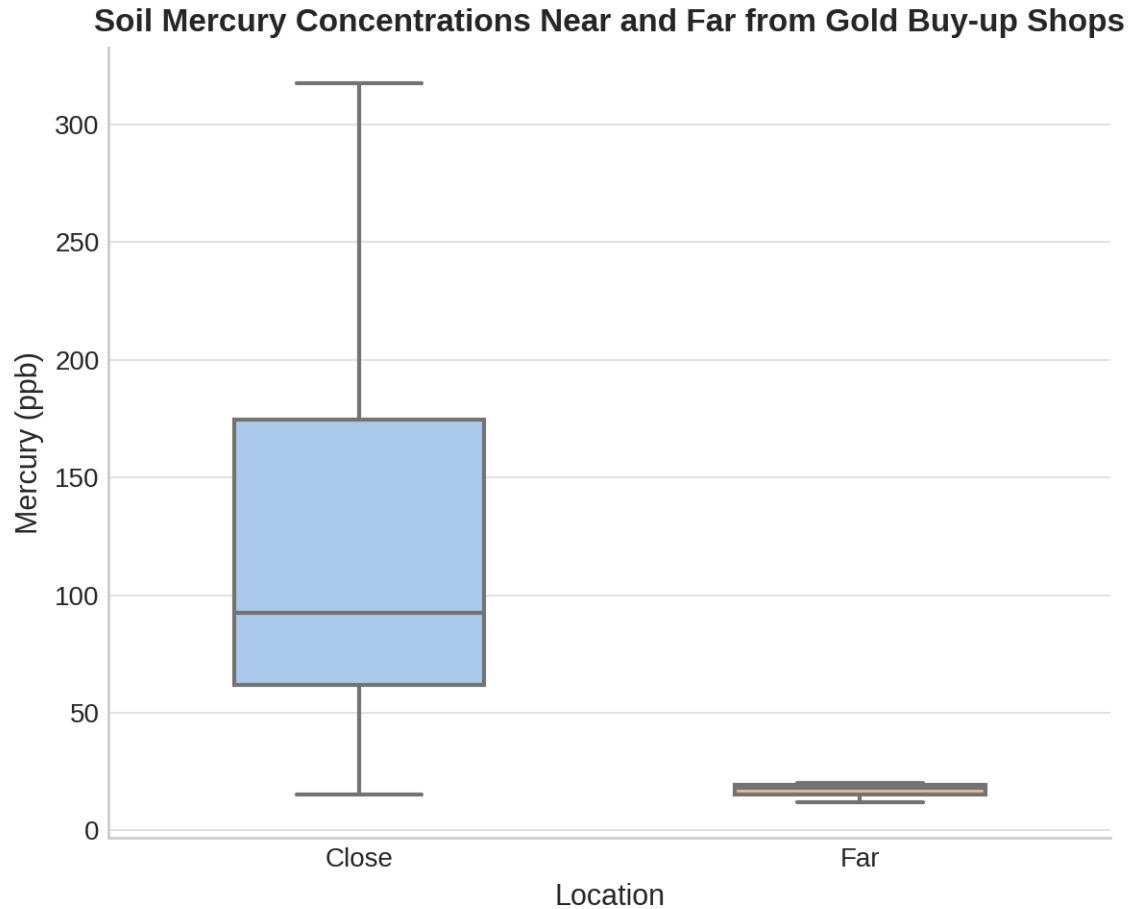


Figure 6. Boxplot comparing mercury concentrations in soil at sites close to (<250 m) and far from (>250 m) gold buy-up shops in Paramaribo.

When grouped by distance to gold buy-up shops, clear differences emerged. The “close” group (n = 13) had a mean mercury concentration of 122.9 ppb (SD = 91.4 ppb), while the “far” group (n = 3) had a much lower mean of 16.9 ppb (SD = 4.3 ppb). Thus, soils in close proximity to gold buy-up shops exhibited, on average, mercury levels roughly seven times higher than soils farther away.

Figure 6 presents a boxplot comparing mercury concentrations in soil between the two groups. The plot highlights both the median difference and the variability within the “close” group, reflecting the high values observed at site 4 and its vicinity.

### Normality Check (Shapiro-Wilk)

- Close samples: borderline normal ( $p = 0.060$ , just above 0.05)
- Far samples: normal ( $p = 0.44$ )

### Independent t-test (Close vs Far)

- $t = 4.16$
- $p = 0.0013$

### Mann-Whitney U Test (non-parametric)

- $U = 37.0$
- $p = 0.014$

To assess the significance of these differences, both parametric and non-parametric tests were applied.

- A Shapiro–Wilk test indicated that data from both groups were approximately normally distributed ( $p > 0.05$ ), although the small sample size for the “far” group limits this conclusion.
- An independent-samples t-test revealed a statistically significant difference in mercury concentrations between close and far sites ( $t = 4.16$ ,  $p = 0.0013$ ).
- A Mann–Whitney U test, which does not assume normality, confirmed this result ( $U = 37$ ,  $p = 0.014$ ).

Both tests strongly suggest that soils near gold buy-up shops contain significantly higher concentrations of mercury than soils farther away.

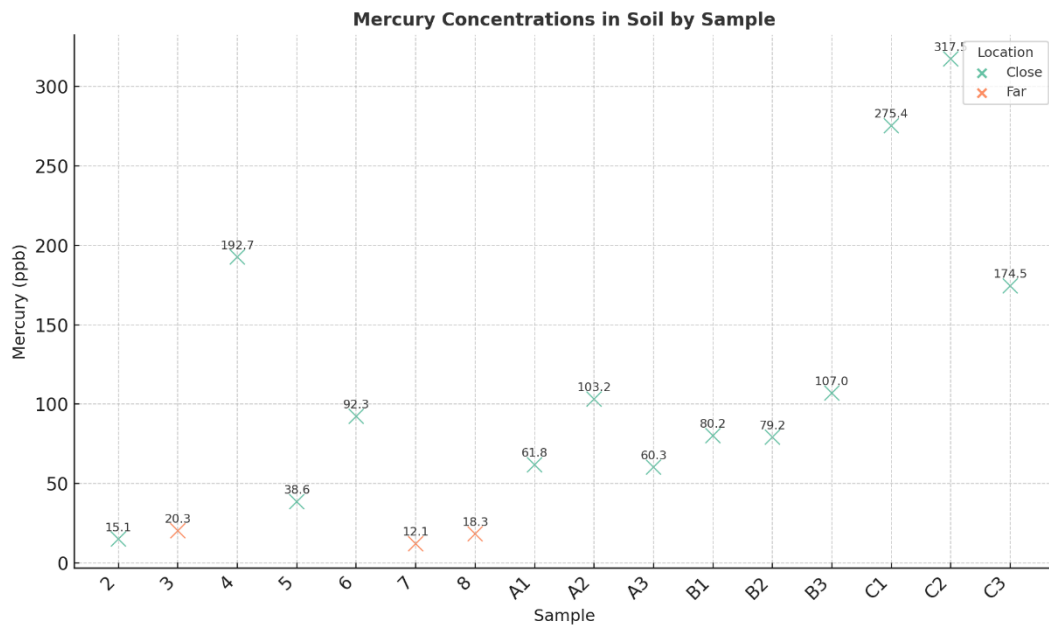


Figure 7. Scatter plot of mercury concentrations in soil by sample. Elevated values are clearly visible at Site 4 and nearby locations (A, B, and C).

Figure 7 provides a scatter plot of individual sample values, making it clear that the highest mercury concentrations were localized to one specific area.

The null hypothesis ( $H_0$ ), which stated that there is no significant difference between the two groups, was tested against the alternative hypothesis ( $H_1$ ), which stated that a significant difference exists.

Results from Welch's t-test showed a statistically significant difference in mean mercury concentrations between the groups ( $t = 4.16$ ,  $p = 0.0013$ ). This was further confirmed by the non-parametric Mann–Whitney U test ( $U = 37$ ,  $p = 0.014$ ). Given that both tests produced p-values below the significance threshold of 0.05, the null hypothesis was rejected in favor of the alternative. These results indicate that soils near gold buy-up shops contain significantly higher concentrations of mercury compared to soils farther away.

## **4.4 Discussion**

### **4.4.1 Mercury in Surface Water**

The results of this study showed that mercury was not detected in any of the ten surface water samples collected in northern Paramaribo, regardless of proximity to gold buy-up shops. This finding was confirmed by two independent laboratories, strengthening confidence in the outcome.

At first glance, the absence of detectable mercury in surface water may seem surprising, given the documented use of mercury in artisanal gold processing. However, this observation directly addresses the first research sub-question, showing that mercury concentrations in surface water near gold buy-up shops are not measurably different from those in unaffected areas. In both cases, values fell below detection limits, indicating no measurable elevation in water concentrations.

This outcome is consistent with findings from other studies which note that mercury binds strongly to soils and sediments rather than remaining dissolved in water (Esdaile & Chalker, 2018; Ouboter et al., 2012; UN Environment, 2019). Another factor is detection limits: laboratories report “non-detect” when concentrations fall below instrument sensitivity. Thus, it is possible that very low levels were present but below quantifiable limits. From a risk perspective, such levels would likely be negligible compared to soils.

### **4.4.2 Mercury in Soil**

Unlike the water samples, the soil results demonstrated a very different tendency. Elevated mercury levels were observed in soils near gold buy-up shops, with mean concentrations of 123 ppb compared to 17 ppb in control soils farther away. This difference directly addresses the second research sub-question, which asked how concentrations differ between impacted and control areas. Statistical testing confirmed the difference as highly significant, leading to rejection of the null hypothesis. In other words, soils near gold-processing businesses are measurably more contaminated.

Localized hotspots underline this finding further. At sample site 4, mercury concentrations exceeded 190 ppb in the first sample, and replicate samples (A, B and C) in the surrounding area reached as high as 317 ppb. Such clustering points to localized inputs are most likely linked to mercury handling and disposal practices.

Analyzing the results of Figure 5, it was observed that concentrations of mercury of A, B and C demonstrated a tendency. The mercury levels increased from A to C (Figure 3), which could be related to the flow of current of the gutter. This could also indicate higher mercury concentrations in samples going further in the direction of A to C.

These findings echo reports from other regions of the world, where soils near artisanal or small-scale gold-processing sites often contain elevated mercury, sometimes several orders of magnitude higher than background levels (Esdaile & Chalker, 2018; Telmer & Veiga, 2009). Soils act as long-term reservoirs of mercury, binding it to organic matter and mineral particles. Over time, microbial activity may convert inorganic mercury into methylmercury, which is far more toxic and bioavailable (Basu et al., 2014). This means that even in the absence of detectable water contamination, soils represent a hidden but significant risk.

These results also provide a clear answer to the main research question: soils — but not surface waters — in the vicinity of gold-processing businesses in Paramaribo are elevated in mercury concentrations.

#### **4.4.3 Comparison to International Standards**

The fourth research sub-question asked how measured concentrations compare to international standards. For water, all samples tested negative and are therefore well below WHO's guideline value of 6 µg/L (WHO, 2011) and the U.S. EPA's maximum contaminant level of 2 µg/L (U.S. Environmental Protection Agency (EPA), 2009). For soils, the maximum concentration of 317 ppb is an order of magnitude lower than both the Canadian guideline (6,600 ppb) (Canadian Council of Ministers of the Environment (CCME), 2007) and the Dutch intervention value (6,700 ppb) (Lijzen et al., 2001).

While this comparison suggests that contamination is not yet at alarming levels, caution is warranted. International thresholds may not fully reflect local realities in Paramaribo, where gold-processing shops are situated close to residential areas (UN Environment, 2019). Even lower concentrations could still contribute to health risks if exposure is continuous.

#### **4.4.4 Future Outlook**

Finally, the fifth research sub-question considered future impacts. The evidence suggests that if current practices persist, soils near gold buy-up shops will continue to accumulate mercury over time. This increases the risk that mercury may eventually leach into waterways, particularly during heavy rainfall or flooding, or undergo microbial methylation in sediments. Although current surface water samples show no contamination, this may change in the future.

This highlights the importance of proactive monitoring and preventive measures. Long-term tracking of both total mercury and methylmercury, combined with community awareness and regulation, could help prevent low-level soil contamination from escalating into broader ecological or public health problems.

## **Chapter 5. Conclusion**

This study was set out to evaluate mercury concentrations in surface water and soil near gold buy-up shops in Paramaribo and to determine whether these businesses contribute measurably to local environmental contamination. By combining field sampling, laboratory analysis, and statistical testing, the research provides new insights into the distribution of mercury in an urban Surinamese context and addresses an important gap in the literature, which has largely focused on interior mining areas.

### **Surface water**

The first research question asked about the presence of mercury in surface waters near gold buy-up shops. The results were unambiguous: mercury was not detected in any of the ten surface water samples analyzed. Results obtained from both laboratories reported values below their detection limits, reinforcing the reliability of this finding. This suggests that, at least at the time of sampling, surface waters in northern Paramaribo are not significantly impacted by mercury pollution from nearby gold-processing activities. This aligns with the known behavior of mercury, which preferentially binds to soils and sediments rather than remaining dissolved in the water column.

### **Soil**

The second and third research questions focused on soils and how their mercury concentrations compared between impacted and non-impacted areas. Here, the contrast was striking. While background soils contained low concentrations (mean  $\approx 17$  ppb), soils collected near gold buy-up shops showed significantly elevated levels (mean  $\approx 123$  ppb). Statistical analysis confirmed that this difference was highly significant, rejecting the null hypothesis. Localized hotspots were observed, particularly around sample site 4, where concentrations reached up to 317 ppb. Although these levels remain below international intervention values, they clearly demonstrate that soils in the immediate vicinity of gold-processing businesses are measurably more contaminated. This contamination also signals potential long-term environmental and public health risks, as soils act as reservoirs where mercury can persist, accumulate, and eventually undergo microbial conversion to methylmercury.

### **International comparison**

The fourth research question addressed how the concentrations observed in this study compare with international standards. In terms of water quality, the results were reassuring: all samples were far below WHO (6  $\mu\text{g/L}$ ) and U.S. EPA (2  $\mu\text{g/L}$ ) guideline values for drinking water. For soils, the measured concentrations were also well below the Canadian (6.6 mg/kg) and Dutch (10 mg/kg) thresholds for intervention. However, the presence of hotspots near gold buy-up shops suggests that mercury inputs are ongoing. Over time, these could lead to increasing concentrations, and reliance on international thresholds alone may understate the risks for local communities living in close proximity to contaminated sites.

### **Future outlook**

Finally, the fifth research question considered the likely future impacts if current practices continue. The evidence from this study points to soils as the critical medium where mercury

accumulates. While immediate risks remain limited, continued deposition could further elevate concentrations, thereby increasing the likelihood of methylation, and potentially introducing mercury into aquatic food webs. Without intervention, Paramaribo's soils may become long-term sources of secondary contamination. For this reason, proactive monitoring and preventive measures are essential to safeguard both ecological integrity and human health.

### **Overall conclusion**

Taken together, the results provide a nuanced picture. Surface water currently shows no measurable mercury pollution, but soils near gold buy-up shops already exhibit significant contamination compared to unaffected areas. Although these levels are still below international guidelines, the localized hotspots and statistical evidence of elevated concentrations highlight the role of gold-processing businesses as contributors to urban mercury pollution. This study underscores the importance of soils as long-term sinks for mercury and demonstrates the need for continued surveillance, public health awareness, and policy interventions to prevent further accumulation and protect communities in Paramaribo.

## Chapter 6. Recommendations

Based on the findings of this study, the following recommendations are proposed for research, policy, and practice:

1. **Continued Monitoring:** Regular monitoring of both surface water and soils near gold buy-up shops should be prioritized to detect changes over time. Seasonal sampling is particularly important, as rainfall and flooding may influence the movement and deposition of mercury. Future monitoring efforts should also measure not only total mercury but specifically methylmercury, given its higher toxicity and ability to bioaccumulate in food chains.
2. **Policy and Regulation:** Mercury management in Suriname would benefit from clearer regulatory frameworks. Policymakers should consider establishing soil quality guidelines tailored to local conditions, as international thresholds may not always reflect the realities of Paramaribo's urban environment. Regulations requiring gold buy-up shops and goldsmiths to adopt safe handling, storage, and disposal practices for mercury — potentially through licensing or inspection systems — would also help reduce ongoing inputs.
3. **Public Health Considerations:** Even though measured soil concentrations remain below international limits, chronic exposure through direct contact or incidental ingestion, especially in residential areas, could still pose risks. Awareness campaigns targeting local communities, workers, and shop owners can play a key role in reducing exposure. Such initiatives should explain in accessible language the hazards of mercury and encourage safer practices.
4. **Research and Future Studies:** Further research is needed to build a fuller picture of mercury risks in Paramaribo. Future studies should examine mercury speciation, distinguishing between inorganic mercury and methylmercury, to better assess ecological and health impacts. Linking environmental data to biological monitoring — for example, mercury levels in fish, crops, or human biomonitoring — would clarify real-world exposure pathways. Expanding sampling to other neighborhoods and districts would also help determine whether the patterns observed in this study are localized or more widespread.

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# Appendices

## Appendix A – Raw Data Tables



ANTON DE KOM UNIVERSITEIT VAN SURINAME

Nationale Zoölogische Collectie van Suriname (NZCS)/  
Centrum voor Milieu Onderzoek (CMO)



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Paramaribo, 13 februari 2025

Aanvraag nr: MLO3  
Aanvrager: Bandhoe Shiwam

### ANALYSE CERTIFICAAT

Fles #	Datum sample ontvangst	Datum analyse	[Hg] (µg Hg/L)		Gemiddeld [Hg] (µg Hg/L)
1	11-02-2025	12-02-2025	0.00	0.00	0.00
2	11-02-2025	12-02-2025	0.00	0.00	0.00
3	11-02-2025	12-02-2025	0.00	0.00	0.00
4	11-02-2025	12-02-2025	0.00	0.00	0.00
5	11-02-2025	12-02-2025	0.00	0.00	0.00
6	11-02-2025	12-02-2025	0.00	0.00	0.00
7	11-02-2025	12-02-2025	0.00	0.00	0.00
8	11-02-2025	12-02-2025	0.00	0.00	0.00
9	11-02-2025	12-02-2025	0.00	0.00	0.00
10	11-02-2025	12-02-2025	0.00	0.00	0.00

Opmerking: Toegepaste analysemethode: Cold Vapor Atomic Absorption Spectrometry



Figure 8. Raw data mercury in water NZCS lab

Table 4. Mercury in surface water results Filab NV

250382		ABSORBANCE	CONCENTRATION
SAMPLE ID	SAMPLE REF.	(Absorbance)	(Absorbance)
	Quant. Lim.		0.005
water	Rinse water	0.0001	0.00
std1	Calibration std1	0.0718	5.00
std2	Calibration std2	0.1555	10.00
std3	Calibration std3	0.2509	15.00
std4	Calibration std4	0.3503	20.00
blk	Calibration blank	0.0006	
bk 4-3-25	Sample water	0.0001	
std1	Sample std1	0.0784	
250382-001	1	0.0003	
250382-002	2	0.0000	
250382-003	3	-0.0001	
250382-004	4	0.0001	
250382-005	5	0.0002	
250382-006	6	-0.0001	
250382-007	7	0.0001	
250382-008	8	0.0000	
250382-009	9	0.0000	
250382-010	10	-0.0001	
std2	Sample std2	0.1472	

Table 5. Mercury in soil results Filab NV

250556		ABSORBANCE	CONCENTRATION
SAMPLE ID	SAMPLE REF.	Hg 253.7 (Absorbance)	Hg ug/l (Absorbance)
	Quant. Lim.		0.005
water	Rinse water	0.0001	0.00
std1	Calibration std1	0.0718	1.00
std2	Calibration std2	0.1555	2.00
std3	Calibration std3	0.2509	5.00
std4	Calibration std4	0.3503	10.00
blk	Calibration blank	0.0001	
bk 3-4-25	Sample water	0.0000	
std1	Sample std1	0.0792	
250556-001	1	0.0162	
250556-002	2	0.0137	
250556-003	3	0.0177	
250556-004	4	0.1505	
250556-005	5	0.0318	
250556-006	6	0.0732	
250556-007	7	0.0114	

Acid Preparation: 5 gram soil in 100ml volumetric flask.

Table 6. Mercury in soil results area of interest

250918		ABSORBANCE	CONCENTRATION
SAMPLE ID	SAMPLE REF.	Hg 253.7 (Absorbance)	Hg ug/l (Absorbance)
	Quant. Lim.		0.005
water	Rinse water	0.0000	0.00
std1	Calibration std1	0.0100	1.00
std2	Calibration std2	0.0282	2.00
std3	Calibration std3	0.0828	5.00
std4	Calibration std4	0.1738	10.00
blk	Calibration blank	0.0004	
bk 27-5-25	Sample water	0.0003	
std1	Sample std1	0.0959	
250918-001	1	0.0498	
250918-002	2	0.0660	
250918-003	3	0.2388	
250918-004	4	0.0864	
250918-005	5	0.0652	
250918-006	6	0.2761	
250918-007	7	0.0485	
250918-008	8	0.0898	
250918-009	9	0.1495	
Acid Preparation: 5 gram soil in 100ml volumetric flask.			

## Appendix B – Calibration Curves and Quality Control

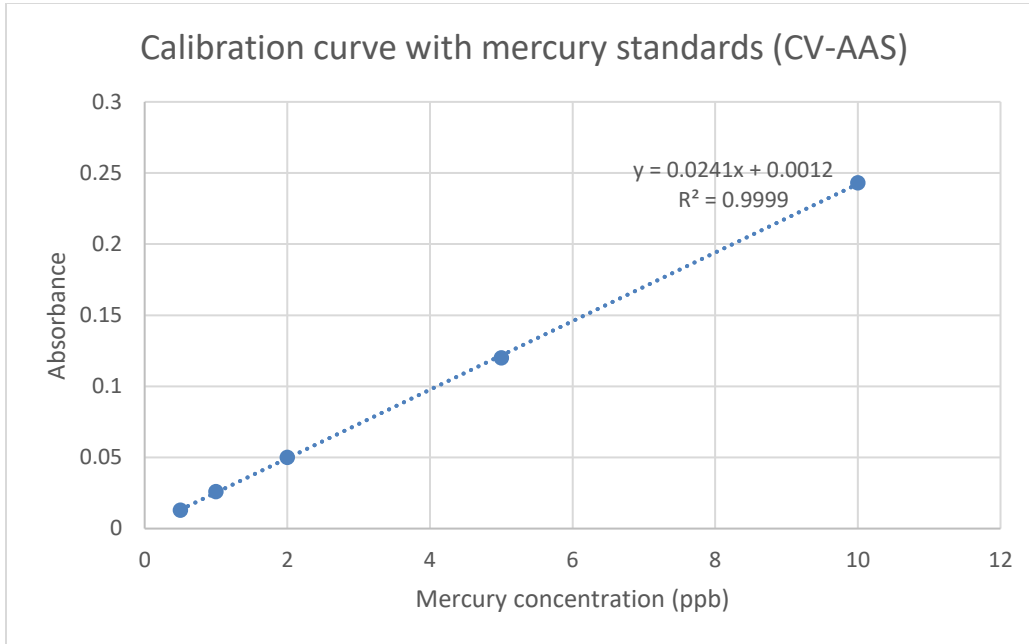


Figure 9. Calibration curve NZCS Lab

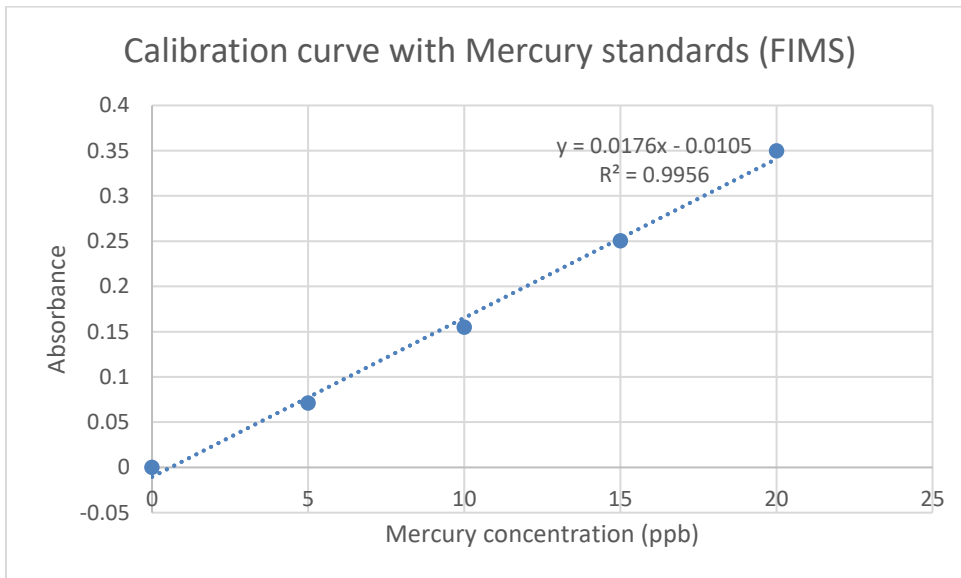


Figure 10. Calibration curve Filab Surface water test

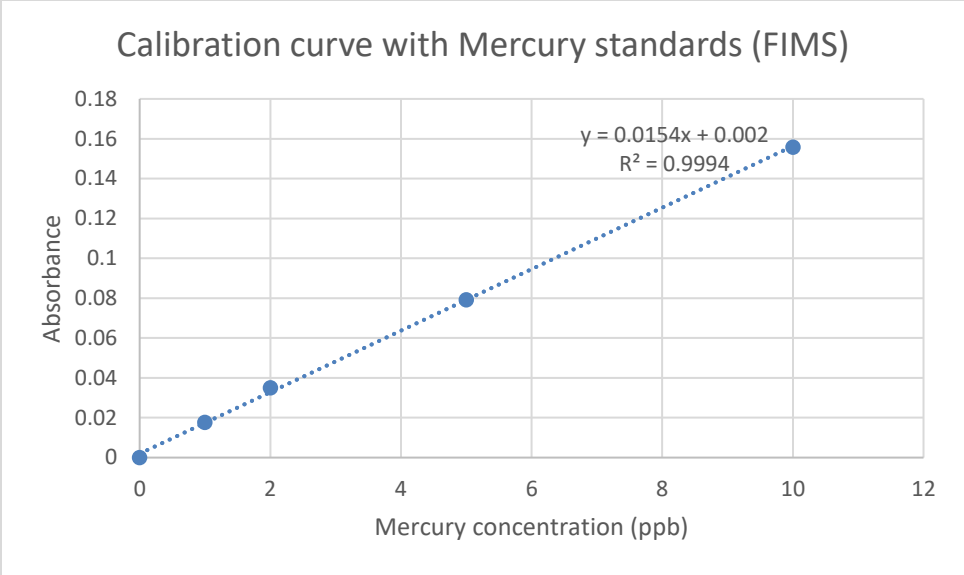


Figure 11. Calibration curve Filab NV soil analysis

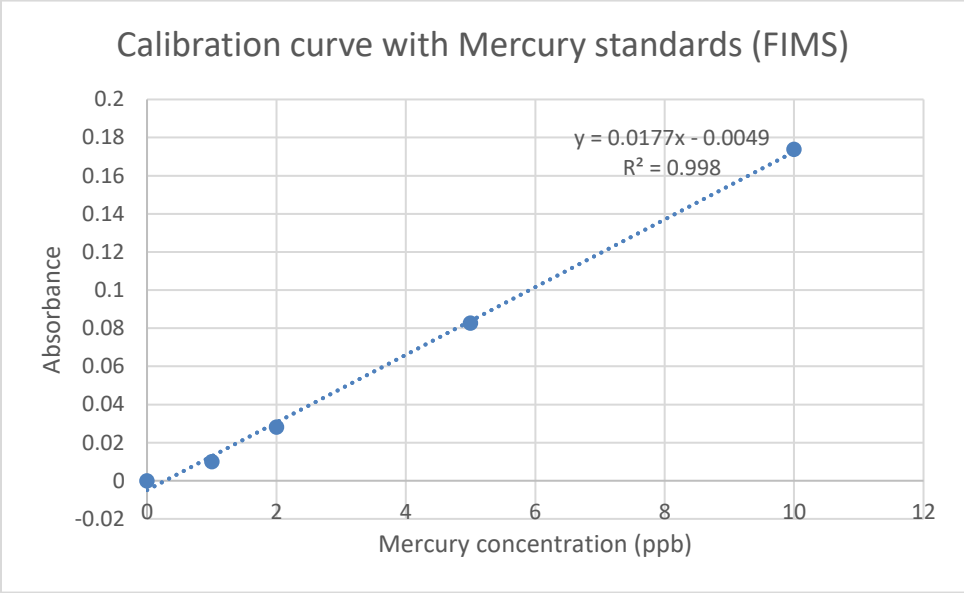


Figure 12. Calibration curve Filab NV soil test area of interest

## Appendix C – Statistical Outputs

```
Result
{'Group Statistics':
  count      mean      std      min      25%      50%      75%      max
Location
Close      13.0  122.908462  91.446438  15.06  61.820  92.34  174.500  317.49
Far        3.0   16.883333   4.272544  12.08  15.195  18.31  19.285  20.26,
'T-test': {'t-statistic': 4.160727455968314, 'p-value': 0.001271497151525854},
'Shapiro-Wilk Close': {'W': 0.8746717252965834,
  'p-value': 0.06042564103446516},
'Shapiro-Wilk Far': {'W': 0.9163755685771102, 'p-value': 0.4397065380290195},
'Mann-Whitney U': {'U-statistic': 37.0, 'p-value': 0.014285714285714285}}|
```

Figure 13. Python results statistical analysis