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“Determination of Lead in Paint via pXRF- and ICP-OES Analysis”

Analysis of legacy paint in playgrounds vs paint currently manufactured

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: 17th of October 2025

Statement of Own Work

I, Selena Breinburg, hereby declare that this thesis, titled “Determination of Lead in Paint via pXRF- and ICP-OES Analysis”, is the result of my own work and research. It has not been submitted, in whole or in part, for any other degree at any institution.

In compliance with academic integrity guidelines, all material, data, and concepts derived from other scholars have been appropriately referenced and acknowledged. The acknowledgments section contains specific mentions of any help obtained during the study process.

I attest that this thesis complies with ethical research norms and am fully aware of the repercussions of plagiarism, data fabrication, and falsification.

Name student: Selena Breinburg

Date: 17th of October 2025

Signature:

A handwritten signature in black ink, appearing to read "Breinburg", with a small flourish at the end.

Abstract

Lead (Pb) is a heavy metal known to cause neurological damage, reduced cognitive development, and behavioral problems, particularly in children. While many countries have introduced strict regulations limiting lead in paints, Suriname does not yet have legally binding standards in place. This study aimed to determine the concentration of lead in yellow, red, and brown local paints currently sold in Suriname and compare these to legacy outdoor paints sampled from playground equipment, using portable X-ray Fluorescence (pXRF) and Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES). The first pXRF (pXRF_Sur) screening was conducted locally, while a second pXRF (pXRF_MU) and ICP-OES analysis took place at Mercer University in the United States. The comparison of analytical techniques showed that the pXRF_Sur and the pXRF_MU strongly correlated, however the pXRF_Sur tended to underestimate the concentrations at higher levels. And compared to the ICP-OES results the pXRF_MU underestimates the values. The findings revealed that legacy paints collected from playgrounds contained significantly higher lead concentrations, approximately 65% of the legacy paint samples contained lead levels exceeding the UNEP proposed limit of 90 ppm. With the ICP_OES analysis concentrations as high as 160979.86 ppm were found in yellow and 143547.47 ppm in red legacy paint samples. In contrast, the ICP-OES, with a practical lead in paint limit of detection of 33.33 ppm, did not detect lead in any of the new paint samples. This suggests they are well within safe range; however, it is still possible that trace amounts of lead were present, just too low for this analysis to reliably pick up. These results indicate that older painted surfaces in public playgrounds may still pose a lead exposure risk to children, underlining the importance of regular inspections and maintenance. The findings of this study suggest that it would be safe to repaint the playgrounds using the new local or imported paints.

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List of Abbreviations and Acronyms

Abbreviation	Definition
AdeKUS	Anton de Kom University of Suriname
BBB	Blood-Brain Barrier
BOG	Bureau Openbare Gezondheidszorg (Bureau of Public Health)
Ca ²⁺	Calcium(II) ion
ED-XRF	Energy Dispersive X-ray Fluorescence
EPA	Environmental Protection Agency
HNO ₃	Nitric acid
HUD	Housing and Urban Development
ICP-OES	Inductively Coupled Plasma - Optical Emission Spectrometry
IQ	Intelligence Quotient
IQR	Interquartile Range
LOD	Limit of Detection
NIST	National Institute of Standards and Technology
Pb	Lead
Pb ²⁺	Lead(II) ion
PbCrO ₄	Lead(II) Chromate
Pb ₃ O ₄	Lead(II,IV) Oxide
PbCO ₃	Lead(II) Carbonate
ppm	Parts per million
pXRF	Portable X-ray Fluorescence
pXRF_MU	Portable X-ray Fluorescence measured at the Mercer University
pXRF_Sur	Portable X-ray Fluorescence measured in Suriname
SDD	Silicon Drift Detector

SMART	Specific, Measurable, Achievable, Relevant, Time-bound
SRMs	Standard Reference Materials
UNEP	United Nations Environment Programme
WHO	World Health Organization
XRF	X-ray Fluorescence

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Chapter 1. Introduction

1.1 General Overview

Lead (Pb) and its compounds continue to be major environmental pollutants, particularly in developing nations. Although the dangers of lead exposure are well known, lead-based paints are still in circulation today, posing ongoing health threats — especially to young children. This thesis focuses on the presence of lead in paint products and the risks associated with their use, particularly in the context of Suriname.

1.1.1 History of Lead in Paint

The use of lead dates back to ancient Rome, where it appeared in everyday materials such as cosmetics, pewter utensils, paints, and even as additives in food and wine. A variety of chemicals were used over the years to achieve the colors in paint, and lead being one of them. Lead-based paint gained popularity during the colonial era and reached its peak around the 1920s, when it was considered both affordable and long-lasting (*Milton A. Lessler, 1988*).

In the 1950s, when the first lead limitations were implemented, things started to change. For example, the city of Baltimore banned the use of lead paint in interiors as early as 1951. A countrywide limitation followed, but it was just optional. Prior to 1978, lead-based paint was a legal product that was in high demand. Until the mid-1970s, federal, state, and local governments in the United States still allowed the use of lead-based paints in public buildings (“*Safe Air Fast*”, 2015). As of March 2023, just 93 countries had legally enforceable rules to restrict the manufacturing, import, and sale of lead paints, despite the fact that the detrimental effects of lead in paint had been known about since at least the 1890s (*United Nations Environment Programme [UNEP], 2020*).

1.1.2 Benefits of Lead in Paint

Paint producers widely favored lead additives due to the various functional benefits they provided. One of the main reasons it was added to paint is for its color and opacity. Different compounds gave distinct shades: lead (II) chromate (PbCrO_4) produced yellow pigment, lead (II, IV) oxide, (Pb_3O_4) produced red pigment, and lead (II) carbonate (PbCO_3) gave paints their

classic white tone (Völz & Hans, 2000). Furthermore, it was used for the strong hiding power, which meant fewer coats of paint were needed to achieve full coverage. Lead compounds enhanced the strength of paints, improving their resistance to weathering, moisture, and sunlight, which helped surfaces stay intact for longer periods. Additionally, lead compounds offer protection against corrosion and inhibit the growth of mold and mildew, making them especially popular for outdoor applications on playgrounds, fences, and metal structures (Environmental Protection Agency [EPA], 2024). Although these qualities explained the widespread use of lead paints, they also delayed recognition of the serious health risks that accompanied them.

1.1.3 Lead Exposure and Health

1.1.3a Physiological and biochemical effects of lead accumulation

Lead (Pb) does not degrade naturally, making it nearly impossible to remove completely once it enters the environment. Lead toxicity and lead accumulation in humans is a major health concern. As Collin and coworkers (2022) highlight, Pb impairs nearly all the bodily organs' abilities to function:

- *Impact on the nervous system*

Among all body systems, the nervous system is most affected by Pb exposure. Acting as a neurotoxin, it can lead to severe conditions, including paralysis or, in extreme cases, death. Pb has a half-life of two to three years in brain tissue and about thirty days in blood. When Pb^{2+} ions cross the blood–brain barrier (BBB), they can substitute for Ca^{2+} ions, disrupting the activity of brain endothelial cells and impairing barrier functions. This process is linked to cognitive deficits in children, including reduced IQ. Severe cases may lead to encephalopathy, where brain function progressively declines, with symptoms such as headaches, poor memory, short attention span, and hallucinations.

- *Impact on the skeletal system-Bone*

Bones serve as the largest reservoir for Pb in the human body. Exposure through both environmental and occupational sources results in the accumulation of Pb^{2+} within the bone matrix. Because bone stores Pb for long periods, it represents the tissue with the highest concentrations, which can later be released back into the bloodstream.

- *Impact on the reproductive system*

The reproductive system is also highly sensitive to Pb exposure. In women, high blood lead concentrations have been associated with pregnancy complications such as miscarriage, low birth weight, and developmental issues in infants. In men, Pb disrupts sperm health, causing abnormalities in shape, reduced motility, and lower sperm counts, all of which decrease fertility.

- *Impact on the hematopoietic system*

The hematopoietic system, which maintains the continuous production of blood cells, is strongly affected even at low exposure levels. Pb interferes with hemoglobin production by blocking key enzymes in the heme synthesis pathway. It also weakens red blood cell membranes, shortening their lifespan. These effects lead to anemia; at higher exposures, Pb can cause hemolytic anemia, where red blood cells are destroyed faster than they are replaced.

1.1.3b Lead effects on children

Children are exposed to a number of health concerns, one of which is low-level chronic lead exposure. According to data from the US-Environmental Protection Agency (EPA) and Housing and Urban Development (HUD), more than 600,000 children between the ages of six months and six years have blood lead levels higher than 25µg/dl. These kids may experience attention deficit disorder, learning disabilities, and IQ deficits. The main way that kids are exposed to lead is through consuming paint that contains lead compounds. Children who live in homes where lead-based paint is present may be exposed by ingesting paint chips or by chewing on painted surfaces. However, the majority of exposure occurs when the paint deteriorates and releases lead-containing dust into the air. Exposure to low levels of lead can cause cognitive deficits in children (reduced IQ) and behavioral changes such as reduced attention span and increased antisocial behavior. (*World Health Organization [WHO], 2023*)

1.1.4 Lead in Paint Laws

Establishing national paint regulations remains the most effective approach to minimize lead exposure from paints. These laws typically set legal limits on the allowable concentration of lead in paints and provide enforcement mechanisms such as penalties for violations. In 2011, the United Nations Environment Programme (UNEP) and the World Health Organization (WHO)

launched the Lead Paint Alliance, a voluntary global partnership aimed at accelerating progress toward eliminating lead-based paints. Its primary goal is to promote the gradual phase-out of lead-containing products and ultimately protect both children and workers from exposure (*UN Environment Programme*, 2018). The world map of countries that have legally binding laws for lead in paint shown in Figure 1 (colored blue), proves that this has been going in the right direction. The 2023 reports of the WHO state that a total of 93 countries have laws limiting the content of lead in paint and 19 countries were in the final stages of drafting lead paint laws (*World Health Organization [WHO]*, 2023).

Figure 1 gives a clear overview that the largest group that does not have any regulations (colored orange) or laws yet, is in Africa. Only 10 countries have laws, 34 countries do not, and the remaining 10 have not confirmed their status. Zooming in on South America, 3 of the countries have not confirmed their status and Suriname is the only one that is confirmed not to have any laws or regulations for lead in paint. According to the UN Environment’s “Model Law and Guidance for Regulating Lead Paint”, the suggested upper limit for total lead concentration in paint is 90 ppm. But worldwide the existing lead limits range from 90 ppm in the United States, Singapore, and China to 1,000 ppm in India (“*Update on the Global Status of Legal Limits on Lead in Paint September 2018*”, 2018). For the purpose of this study, the regulatory limit of 90 ppm established by the US-EPA will be used as the reference threshold for lead in paint.

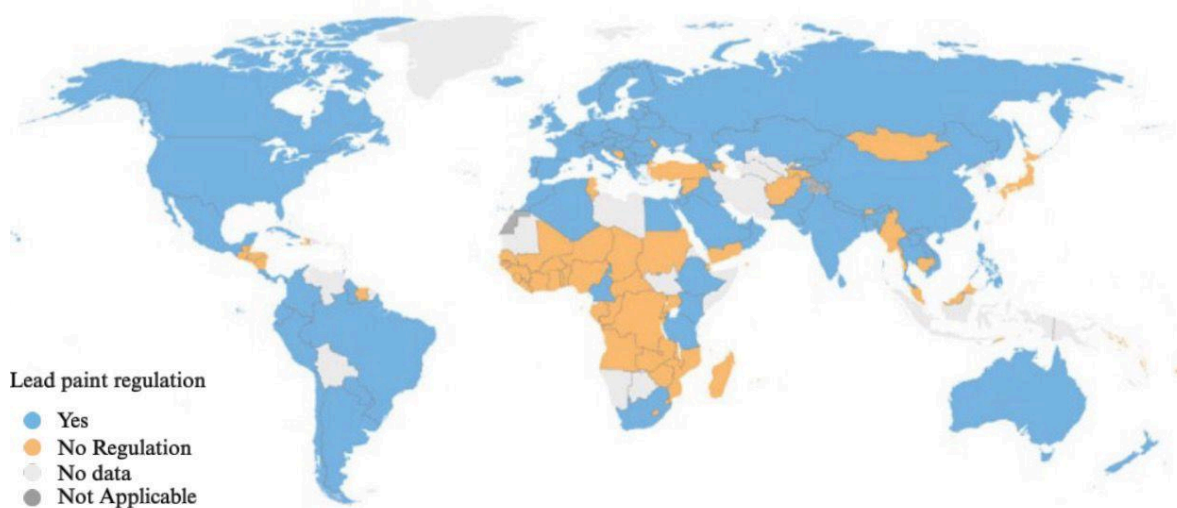


Figure 1: Legally binding controls on lead paint, as of 31 March 2023 (“Update on the Global Status March 2023 of Legal Limits on Lead in Paint”, 2023)

1.2 Problem Statement

The use of lead in paint dates back decades. It was valued not only as a pigment but also because it reduced drying time, improved durability, and increased resistance to moisture. These qualities made it an important component of paints for many years. Lead compounds in the paint layer do not evaporate and generally remain stable as long as the surface is intact. Problems arise when the paint film is disturbed — for instance, through sanding or scraping — as this creates dust and chips that contain lead and can contaminate the surrounding environment. The lead is more easily absorbed through the mouth and nose due to the small particles produced during the sanding process. Children are particularly vulnerable to lead exposure. Even low concentrations can impair cognitive development, leading to reductions in IQ, shortened attention spans, and increased risks of behavioral problems like hyperactivity or aggression (*Ramírez Ortega et al., 2021*). Children can easily absorb paint flakes with hand to mouth gestures, thus making it important to test paints in areas where children are actively in physical contact, in this case playgrounds. In Paramaribo and Commewijne, there are numerous public and private school playgrounds with very old flaking layers of paint, used by children on a daily basis. Latest data showed that Suriname is the only confirmed country in South America with no lead in paint laws (“*Update on the Global Status March 2023 of Legal Limits on Lead in Paint*”, 2023). There are multiple locally produced and imported paints sold in stores in Suriname, so it is of importance to determine whether these are lead-free or have concentrations exceeding the US mandatory lead limit of 90 ppm (United States Consumer Product Safety, n.d.). The focus is on the colors yellow, red and brown, since Lead (II) chromate (PbCrO_4) and Lead tetroxide (Pb_3O_4) are popular pigments used in yellow and red paint respectively (*Sandberg, n.d.*). A combination of these colors is used to construct brown paint. The handheld XRF Explorer 3000 provides a fast and efficient method for detecting lead in paint. However, its unknown limit of detection forms a limitation to detecting lead at lower levels. To ensure more accurate results, this study also made use of a second technique: Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES).

1.3 Main Research Question and Sub-questions

1.3.1 Main Research Question

What concentration of lead is to be detected in yellow, red and brown paints, purchased in Suriname in 2024, versus legacy outdoor paints in playgrounds, using pXRF and ICP-OES?

1.3.2 Sub-Questions

- Do the colors yellow, red and brown paint of locally sold paint contain lead?
- Do year old paints from playgrounds in Paramaribo and Commewijne contain lead?
- Does the lead in new paint exceed the US regulatory limit of 90 ppm?
- Does the lead in old paint of playgrounds exceed the US regulatory limit of 90 ppm?
- Does the concentration of lead differ in locally produced versus imported paint?
- Do the results of the handheld XRF-Explorer 3000 differ significantly from the ICP-OES method?

1.4 Goals

The goal of this study is to determine the presence of lead in red, yellow and brown colored paint in a fresh batch of locally sold paints in comparison to legacy paints from public and school playgrounds. The measurements will be done using two different methods: pXRF analysis in Suriname and ICP-OES in the United States of America. Although the project initially began in 2024, it will be finalized and submitted by August 2025.

This will be done by:

1. Collecting legacy paint samples from public and school playgrounds and analyzing these locally with the Surinamese Skyray Instruments Explorer 3000 pXRF (pXRF_Sur).
2. Purchasing red, yellow and brown, locally sold paints of various brands and measuring the lead content using the pXRF_Sur.
3. Shipping the samples of the new and legacy paint to Mercer University in the USA to measure the lead content using the Olympus Vanta C pXRF analyzer (pXRF_MU) and the Perkin Elmer (PE) Optima 8300 Concentric ICP-OES.

1.5 Relevance of the Project

According to the 2019 US-EPA's report on lead paint laws in Latin America and the Caribbean, Suriname is the only confirmed country in South America that has no laws for lead in paint (Sellars, 2019). Thus, the importance of this study is that the results of this research project can urge a change in this. The focus is on outdoor playgrounds because over the years paint deteriorates from exposure to sunlight, heat, moisture, and normal wear and tear. If that paint contains lead, it will easily spread and create a hazardous environment for children who are vulnerable to ingestion.

If this study confirms that the older paints used in public playgrounds contain lead, it would be an important signal that action is needed. The results can be used to encourage schools, playground owners, and—most importantly—local authorities to take responsibility for identifying and controlling these hazards. This could involve replacing or safely removing old paint and ensuring that safer, lead-free alternatives are used moving forward to help reduce the risk of lead poisoning in children. Therefore, it is also necessary to determine if the locally sold paints contain lead in concentrations that surpass the global standards.

1.6 Thesis Outline

Table 1. An outline of the thesis with descriptions of each section

Chapter	Description
1. Introduction	This chapter provides the overall background and context of the study, explaining the global and local concerns around lead in paint. It highlights the health risks associated with lead exposure, for the most vulnerable group namely children, and outlines the main objectives and research questions that guided this thesis.
2. Literary Review	Reviews relevant scientific studies and reports on lead contamination in paints, including previous findings from other countries and any known data for Suriname. It also takes a closer look at the health effects of lead exposure, especially in

	<p>children, such as developmental delays, learning difficulties, behavioral problems, and damage to the nervous system. The review further outlines global regulatory frameworks for lead in paint and highlights commonly used analytical techniques, including pXRF and ICP-OES, that help detect and quantify lead content in painted materials.</p>
3. Materials & Methods	<p>Describes in detail how the study was carried out. It includes the approach taken to collect paint samples from different sites, the procedures used to prepare the samples for analysis, and the step-by-step methods followed for pXRF measurements and ICP-OES digestion and analysis. It also explains how data was processed and how the statistical comparisons were made.</p>
4. Results & Discussions	<p>Presents the main findings of the research, such as measured lead concentrations in different paint categories and comparisons between old (legacy) and new paints, local and imported brands, as well as the comparison between analytical techniques. This chapter also interprets what these results mean in a broader context, compares them to similar studies, and discusses possible reasons behind the trends observed.</p>
5. Conclusion	<p>Summarizes the key insights drawn from the study and answers the original research questions.</p>
6. Recommendations	<p>Discusses the limitations of the research, the implications for public health and regulatory actions, and offers recommendations for future studies or monitoring efforts in Suriname.</p>

Chapter 2. Literature Review

Each entry in this section represents one article from the peer-reviewed literature, one operating manual, or one paper from the grey literature, followed by a brief summary of major findings relevant to the work documented in this thesis.

2.1 Lead in Paint Study Israel

Lead in spray paint and painted surfaces in Israel (Berman, et al., 2018)

Berman et al. (2018) conducted a pilot study in Israel to evaluate lead levels in playground paints. Samples were collected from a variety of surfaces, including metal, plastic, and wood, at heights accessible to children in the cities of Tel-Aviv, Hadera, and Bnei Brak. A handheld portable X-ray fluorescence (pXRF) analyzer was used to measure lead levels in the collected paint samples. The researchers found that approximately 90% of the tested surfaces contained detectable amounts of lead. At the time there were no regulations for lead in paint of surfaces in Israel, but the concentrations found, exceeded the US regulatory limit for lead in paint (90 ppm) in 80% of tested surfaces on wooden picnic tables and benches, and 88% of surfaces in playgrounds. This study showed possible sources of lead exposure especially for children, however acute childhood lead poisoning is uncommon in Israel. Thirteen incidents of pediatric lead exposure were documented in 2007, all of which were children between the ages of six and twelve, according to a report from the Israel Poison Information Center. Current estimates of population-level lead exposure are unavailable since children's blood lead levels are not routinely monitored in Israel. The country's dry, hot Mediterranean climate likely accelerates paint degradation, increasing the chances that eroding flakes and dust will contaminate surrounding soil and sand with lead. Children spend quite some time outdoors, in the playgrounds, so it was of great importance that awareness was raised about this issue and regulations and standards were made for the concentration of lead in paint. These were all recommendations made after this study.

2.2 Lead in Paint Study South West England

Lead and other toxic metals in playground paints from South West England (Turner, Kearn, & Solman, 2015)

In Southwest England, researchers analyzed playground structures for metals such as Pb, Cr, Cd, and Sb. For on-site testing, smooth paint areas were first wiped clean and dried before measurement. Then the XRF nose, including measuring window and proximity sensor, were securely in place against an 8 mm-diameter region, the trigger mechanism was depressed to analyze the surface for 200 seconds (100 seconds for the main and low energy bands). For the laboratory measurements the XRF was mounted on a benchtop accessory stand and linked to a laptop via USB and a remote trigger in order to analyze paint samples. With the use of a pair of tweezers, samples were deposited onto a SpectraCertified Mylar polyester 3.6 μm film, exterior facing down. The slide was then positioned centrally over a 3 mm small-spot collimator above the XRF detector. Lead was detected in 102 out of 242 cases, with concentrations ranging from 10 to 152,000 $\mu\text{g/g}$. The highest concentrations of Pb were found in yellow and red paints. These concentrations were found on a variety of structures and equipment, including gates, flooring lines, railings, handles of climbing frames and seesaws, and the interior of a model train. The paints containing the highest lead concentrations were often peeling and appeared to be relatively new coatings. The authors concluded that lead levels in many playground paints exceeded both current and older regulatory limits.

2.3 Quantification of lead in new paints

Standardization of pXRF via ICP-OES for lead in new paint (Seney et al., 2024)

In a recent study that focused on new paints, a comparison was made between lead concentrations measured using a handheld Olympus Vanta C pXRF analyzer and results from ICP-OES analysis. In that study, the paint samples were first dried, ground up to make them uniform, and then digested in nitric acid before being analyzed by ICP-OES. About 0.150 g of paint was used for each digestion, and a certified reference material (NIST 2580) helped verify the accuracy of the method. Those same samples were also tested with pXRF. Results indicated that the pXRF tended to give readings about 27% lower than ICP-OES; however, a strong correlation was observed between the two methods (R^2 greater than 0.98). When correction equations were applied, the adjusted pXRF results aligned closely with the ICP-OES measurements, differing by only about $\pm 4.4\%$. The pXRF device in that study also had a detection limit of around 3 ppm, which is low enough to see if a paint meets common regulatory limits like 90 ppm. This study is a good example of how even though pXRF might slightly

underestimate lead levels, it can still be a dependable screening tool, especially when checked against a more precise technique like ICP-OES. In this current thesis, where both methods were used, it supports using pXRF for quick field measurements, as long as the potential underestimation at higher concentrations, especially larger than the regulatory limit of 90 ppm, is kept in mind.

2.4 Techniques for measuring Lead in Paint

2.4.1 A XRF Analysis (*XRF Analysis for lead in paint* (“*What Is XRF (X-Ray Fluorescence) and How Does It Work?*”, 2020)

X-ray fluorescence (XRF) has long been used over decades to measure lead concentrations in paints due to its speed, accuracy, and non-destructive nature, which eliminates the need for sample preparation. In XRF, a material is exposed to high-energy radiation, typically X-rays or gamma rays. This excites the atoms in the sample, causing them to release secondary, or “fluorescent,” X-rays. Since each element produces X-rays with a unique energy pattern, these signals can be measured by the analyzer to identify which elements are present and in what relative amounts.

Principle of XRF is the following:

An X-ray tube generates high-energy radiation that is directed at the sample surface. When a high-energy photon strikes an atom, it can eject an inner-shell electron, leaving a vacancy that is later filled by an electron from a higher energy level. The atom then re-stabilizes as an electron from a higher-energy shell falls into this lower-energy position. The energy difference between these two states is released in the form of a fluorescent X-ray. Because the energy of this emitted X-ray is specific to each element, analyzing these emissions forms the basis of XRF measurement.

2.4.2 *Handheld XRF Analyser Explorer 3000* (Skyray Instruments, n.d.)

The use of handheld XRF analyzers is extensive in the manufacturing of electronic components, verification of packaging materials, testing for hazardous substances in various batteries, toys, stationery, children's products, and other industries. The Explorer 3000 model is designed for field portability; it is compact, lightweight, and includes a sturdy travel case for secure transport.

Another benefit is that sample preparation is not necessary, raw materials can be measured directly. For more accuracy the benchtop XRF, shown in Figure 2, is advised. Accuracy is possible thanks to four core components: Miniature X-ray tube, SDD or optional Fast-SDD detector, digital signal processor and multichannel intelligent analysis module.



Figure 2 A benchtop pXRF (Skyray Instruments, n.d.)

2.4.3 Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) (Ghosh et al., 2013)

Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) is a widely used analytical technique for quantifying elemental concentrations in liquid samples with high accuracy and sensitivity. Since becoming commercially available in 1974, it has been widely applied due to its ability to handle complex samples, analyze multiple elements at once, and provide highly accurate results. In this method, the liquid sample is pumped through a nebulizer, which turns it into an aerosol. This aerosol then enters a spray chamber and is carried into a plasma torch fueled by argon gas. The plasma reaches temperatures of up to 10,000 K, which is hot enough to excite the atoms in the sample. When these excited atoms return to their ground state, they release energy in the form of light. Each element emits light at specific wavelengths, and a spectrometer detects and measures this emission to determine the concentration of the element in the sample. A schematic overview of a typical ICP-OES system is shown in Figure 3 below. Because the paint samples in this study had to be digested in acid and turned into a solution before analysis, ICP-OES was the most appropriate method. It helped avoid issues like surface roughness or uneven mixing, which could affect other techniques like pXRF. Plus, its high sensitivity and reliability made it ideal for verifying the results from pXRF screening.

Despite being a more expensive and time-consuming method, its accuracy and precision make it especially valuable in confirming trace amounts of lead in paint.

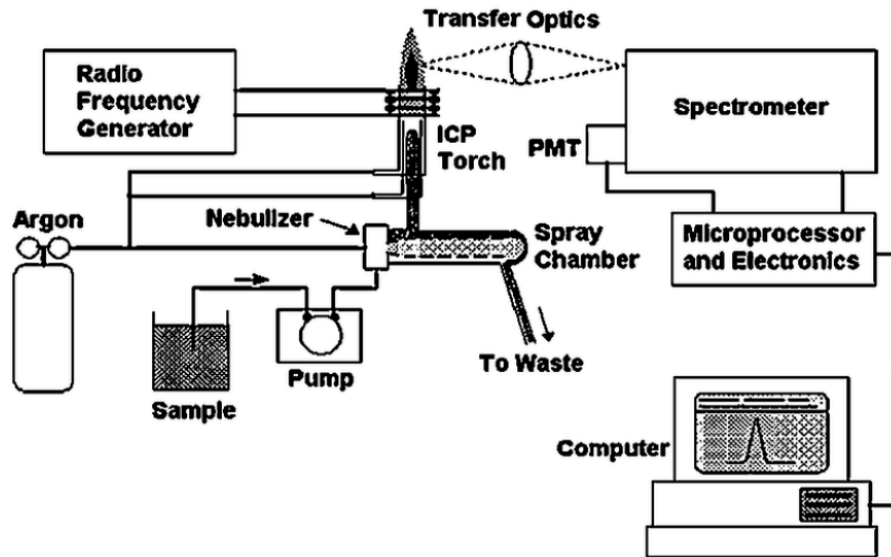


Figure 3 Schematic overview of a typical ICP-OES system (retrieved from Boss and Fredeen, 1997)

Chapter 3. Methodology & Materials of Research

3.1 Materials, Apparatus and Chemicals

3.1.1 Materials

- 6 tins of paint of brand A
- 6 tins of paint of brand B
- 15 tins of paint of brand C
- 27 louvers (20 x 15 cm)
- Dishwashing sponges
- Scissors
- Wooden spatulas
- Ziploc plastic bags
- Cricut precision knives

3.1.2 Apparatus

- Skyray Instruments Explorer 3000 pXRF analyzer
- Olympus Vanta C pXRF analyzer
- Perkin Elmer (PE) Optima 8300
- Perkin Elmer (PE) Optima 8300 Concentric ICP-OES with a SC-4 DX Autosampler.
- Precision mass balance

3.1.3 Chemicals

- Nitric acid, HNO₃ (Sigma-Aldrich)
- Perkin-Elmer (26 multi-element Std Pure: PE No. N9301721)
- National Institute of Standards and Technology (NIST)-Standard Reference Materials (SRMs) 2582, 2711

3.2 Sampling Process

The samples were divided into two main categories: legacy (old) paints and new paints. The collection of legacy paint samples took place over two weeks at public playgrounds and school playgrounds. During the first week, sampling was conducted in the district of Commewijne, while in the second week, it was completed in the capital city of Suriname, Paramaribo. Figure 4 shows the map with the different locations all the samples were conducted from. Samples were collected from all available playground equipment with yellow and red painted surfaces, as these

colors are often linked to higher lead levels. A stainless-steel Cricut precision knife was used to gently scrape the flaking paint from surfaces to avoid contamination. In Figure 5 a collage of the already flaking paint on the equipment from five different locations is shown. The paint samples were then carefully transferred to ziploc bags and labeled.



Figure 4 Overview of visited locations with a playground in Paramaribo and Commewijne



Figure 5 Overview of the flaking paint on the equipment at five different locations

3.3 New Paint Sample Preparation

For the new paint samples, paints from two popular local brands, referred to as Brand 1 and Brand 2, were used in red, yellow, and brown, with two shades of each color. Additionally, an imported Brazilian paint brand, referred to as Brand 3, was included. For the imported paint,

samples were collected in the following colors: black, white, red, yellow, brown, green, blue, and grey.

Each tin of paint was stirred thoroughly with wooden spatulas to ensure uniform consistency before application (Figure 6). Then the soft side of a kitchen sponge was used to apply the first layer of paint on the glass louver. This was set to air dry for 48 hours then the process was repeated three more times for all twelve shades of paint, resulting in 4 layers of paint per sample. In Figure 7 it is illustrated what 2 coats of dried paint looks like on the glass louver. After the paint was fully dried, the layer was carefully removed from the louver with a precision knife and stored in ziploc plastic bags.

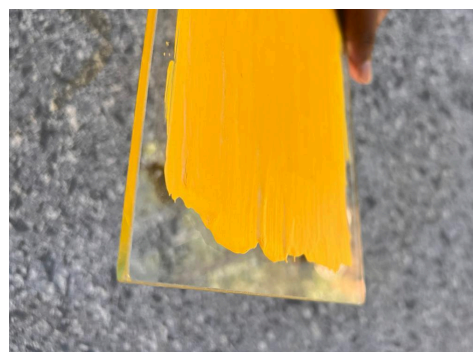


Figure 6. Homogenization process and used equipment *Figure 7. Two layers of paint dried on louver*

3.4 Paint Analysis using pXRF in Suriname

The analysis of all samples was conducted at the Central Laboratory of Suriname's Bureau of Public Health (BOG) using the Skyray Instruments pXRF Explorer 3000. The instrument settings were configured by the lab assistant and are detailed in Table 2. To ensure the pXRF measurements were accurate, the instrument was calibrated by the lab assistant using manufacturer standards, and its performance was verified against a known lead metal standard. This procedure confirmed that the instrument's accuracy was within approximately ± 2.55 ppm. No further sample preparation was required. Each sample was carefully placed on the instrument's mounted top, and measurements were taken over a 100-second timer. First, all new paint samples were analyzed in duplicate, followed by the old paint samples using the same procedure. To prevent cross-contamination, the mounted top was wiped clean after each measurement.

3.5 Paint Analysis using pXRF at Mercer University

These pXRF measurements were carried out in the Kiefer laboratory. The new paint samples were tested using a portable Olympus Vanta C pXRF analyzer that was set up on a field stand. The analyzer used two energy beams—40 kV for 10 seconds and 10 kV for 20 seconds—for each measurement cycle. The instrument automatically calculates uncertainty using a 3-sigma (3σ) threshold, and any values below this threshold are reported as “<LOD”. According to the manufacturer, the theoretical detection limit for lead under ideal conditions is around 3 ppm. Prior to testing, the paint samples were mixed to achieve uniformity and transferred into polyethylene cups sealed with 4 μm Prolene film. All samples were measured in triplicate.

3.6 Paint Analysis with ICP-OES

The ICP-OES measurements were carried out by Professor Kiefer and his lab team, so the exact day-to-day details of the procedure are not available. However, the main steps are known and included. About 0.150 g of each paint sample was digested using a modified ASTM E1645-16 microwave digestion method with a PerkinElmer Titan MPS system, using 5 mL of HNO_3 as the only acid. A certified reference material (NIST 2580) was digested alongside each batch. Digestion involved ramping the temperature to 180 °C within five minutes, followed by a 15-minute hold at that temperature. The digests were then centrifuged at 4000 rpm and 21 °C for 15 minutes, diluted with 2 % HNO_3 , and analyzed using a PerkinElmer Optima 8300 ICP-OES fitted with an autosampler and a SeaSpray nebulizer. Both instrument operation and data acquisition were fully automated, ensuring consistent and precise lead determinations.

Table 2 Specifications of the pXRF Explorer 3000 (Skyray Instruments, n.d.)

Analysis Method	ED-XRF
Detector	25mm ² , 0.3mil. SDD, resolution $\geq 139\text{eV}$
Excitation source	50KV/200uA micro-Ag target and end-window integrated X-ray tube and HV power supply
Measurement time	100 s
Sample type	solid
Detection limit	Down to ppm level

Concentration range	ppm ~99.99%
Control	One-touch test, no need to select specific test mode
Ambient humidity	≤90%
Ambient temperature	-20°C~+50°Cz

3.7 The Bland-Altman and Mann-Whitney U-test

To compare the results from different measurement methods and paint types, two non-parametric statistical tests were used: the Mann-Whitney U-test and the Bland-Altman analysis. Because the lead concentration data did not meet normality assumptions, the Mann-Whitney U test was used as a nonparametric alternative to the independent samples t-test (*Shier, 2004; Statistics by Jim, 2025*). This test ranks all values pooled from both groups and then compares the sum of ranks between them. The U statistic quantifies the degree of separation between the rank distributions (*McKnight & Najab, 2010*). A two-tailed p-value less than 0.05 was interpreted as evidence of a statistically significant difference in the distributions. To support interpretation, the interquartile range (IQR) was calculated — the difference between the 75th and 25th percentiles — which helps visualize how spread-out the middle 50 % of values are (*Rumsey, 2016*).

The Bland-Altman approach is used to evaluate how closely two measurement methods agree. For each sample, the difference between the two readings is calculated and plotted against the mean of those readings. This visualization helps reveal any consistent bias or noticeable pattern between the two techniques. The plot also includes the “limits of agreement,” which mark the interval within which most of the differences are expected to occur. When the majority of values fall within these limits and show only small deviations, it indicates that the two methods produce results that are generally consistent with one another (*Bland & Altman, 1986*).

By combining both methods, conclusions can be drawn on whether the pXRF method yields significantly different values (Mann-Whitney U) and whether those differences are consistent or biased across the measurement range (Bland-Altman).

3.8 Safety

During the sampling process, a N95 face mask was worn to prevent the inhalation of fine paint dust or flakes. Throughout both sample preparation and analysis, protective gloves and safety glasses were also used. In the laboratory, standard personal protective equipment—consisting of a lab coat, gloves, and protective eyewear—was consistently worn to ensure safety during all experimental procedures.

Chapter 4. Results & Discussion

4.1 pXRF Measurements Suriname

4.1A pXRF Suriname Legacy paint results

Table 3 presents the average of the lead concentrations that were measured in duplicate in legacy paint samples using the pXRF device in Suriname. The playgrounds primarily contained yellow and red paint, so these two colors are sorted and the concentration that exceeded the UNEP recommended limit of 90 ppm are bolded.

Table 3. Results of the pXRF measurement in Suriname of legacy paints, with [Pb] exceeding 90 ppm in bold

Legacy Paints			
Red Paint		Yellow Paint	
Sample ID	Lead Concentration (ppm)	Sample ID	Lead Concentration (ppm)
F-RedB	83.0 ± 3.9	F-GeelB	607 ± 3
F-RedHR	25.0 ± 0.3	F-GeelHR	1446 ± 1
BG-RedSS	269 ± 10	F-GeelSW1	8.5 ± 5.0
BG-RedHR	11579 ± 37	F-GeelSW2	2.2 ± 0.4
GB-RedSW	18.6 ± 1.9	BG-GeelSW	31145 ± 33
NA-RedSW	84.4 ± 0.2	GB-GeelSS	40.6 ± 26.9
NA-RedHR	54.3 ± 0.2	BG-GeelHR	238 ± 5
NF-RedHR	11662 ± 84	GB-GeelSW	28648 ± 47
		GB-GeelS	109 ± 6
		GB-GeelHR	125 ± 1
		BG-GeelSS	13607 ± 346
		M-GeelS1	285.70 ± 5.32
		M-GeelSW2	380 ± 0
		NA-GeelSW	17672 ± 107
		NA-GeelHR	34164 ± 57
		NF-GeelS	37905 ± 29

The new paint samples analyzed using pXRF_Sur all displayed lead concentrations far below the 90 ppm regulatory threshold (Appendix A, Table 4), in all measured colors. In contrast, roughly 65 % of the legacy paints exceeded this limit by a substantial margin. As summarized in Table 3, some of the highest concentrations were detected in red legacy paints (up to 11,661 ppm) and yellow legacy paints (up to 37,905 ppm). Historical data from the National Institute of Standards and Technology (1994) indicates that vivid yellow tones were often produced with lead-based pigments such as lead chromate, explaining the elevated Pb levels observed. To visualize this difference, Figure 8 shows a comparison of the lead concentrations in legacy and new paints, as measured with pXRF_Sur.

4.1B Comparing lead concentration in legacy and new paints

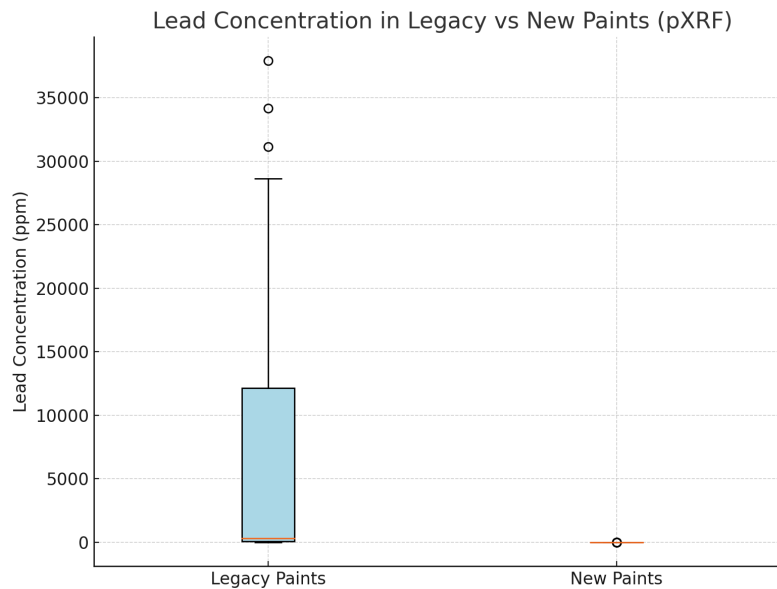


Figure 8. Average lead concentration in legacy and new paints

The results of the pXRF_Sur measurements show a clear and statistically significant difference in lead concentrations between legacy and new paints. As seen in Figure 8, legacy paint samples contain much higher levels of lead compared to the new paint samples. Although the newer paints included a wider variety of colors, this comparison remains valid because the primary goal was to assess whether freshly sold paints comply with current safety standards, especially in contrast to older, unregulated paints. Since the dataset did not follow a normal distribution, the Mann-Whitney U-test was used to compare the two groups. The test produced a U-value of 1.0

with a corresponding p-value of approximately 9×10^{-10} , indicating a highly significant difference. These findings align with expectations, as older paints are more likely to contain high levels of lead due to the lack of strict regulations at the time. While newer paints tend to comply with current safety guidelines, they have been intentionally redesigned to eliminate lead pigments and use organic pigments instead (Eckl et al., 2021).

4.1C Comparing lead concentrations in local vs imported paints

Figure 9 presents a box plot comparing lead concentration distributions in locally produced and imported paints for the colors yellow, red, and brown. The median lead level is higher in imported paints than in local ones, hinting that imported products can sometimes contain more lead. The interquartile range (IQR) is also wider for imported paints, which points to more variability in lead content across those samples.

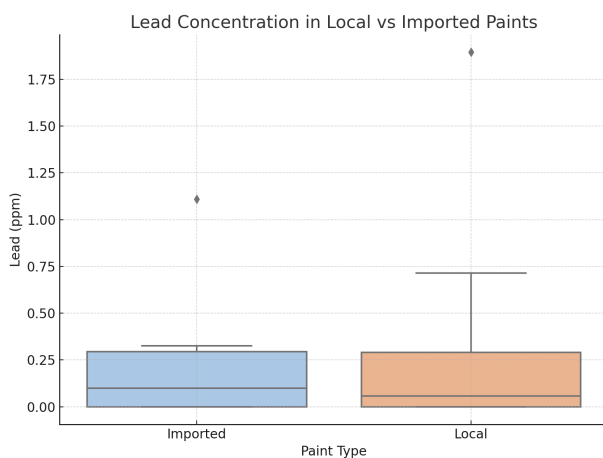


Figure 9. Lead concentrations in local vs imported paints

Both categories of new paint showed very low lead concentrations, with none exceeding 2.84 ppm. The pXRF analyzer used in Suriname operates with proprietary software and methodology, and unfortunately, the manufacturer does not provide a formal limit of detection (LOD) for the instrument under ideal conditions. Because of this, there is no official LOD value available for this specific setup. In this study, we therefore worked with the low values that were retrieved during the analysis of the new paint samples, under the assumption that any lead present below those levels would likely remain undetected by the instrument.

The Mann-Whitney U-test yielded a p-value of 0.922 indicating that there is no statistically significant difference between the lead concentrations in imported and local paints (at a significance level of 0.05). This means that, based on this specific comparison using only yellow, red, and brown paints, both local and imported paints have similar lead content. Comparison across different colors still yielded the same result (Appendix B). This is encouraging and indicates that newer paints, no matter where they're produced, are likely being made according to safety standards. All of the levels found (shown in Appendix A, table 5) were also well below the 90 ppm benchmark set by the UN

4.1D Comparing lead in new local paints: brand 1 vs 2

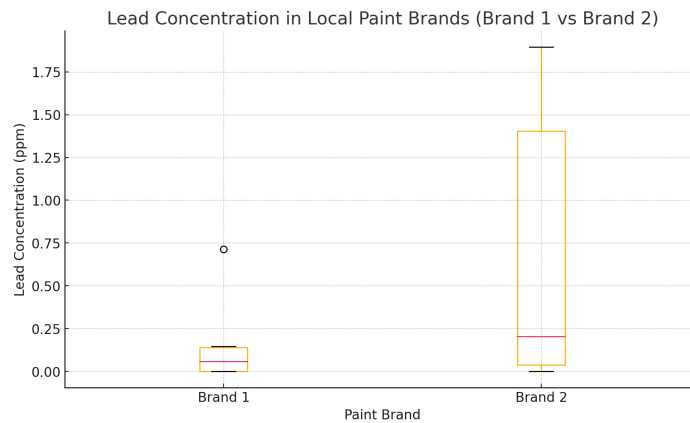


Figure 10. Comparing lead concentrations in two local brands of paint

Figure 10 shows a box plot comparing the lead (Pb) concentrations in two locally produced paints, labeled Brand 1 and Brand 2. The median lead levels for both brands are fairly low, which means most of the samples had only minimal amounts of lead. Brand 2 does show a slightly wider range of concentrations than Brand 1. The outliers in the plot suggest that a few samples had higher lead levels, which could point to inconsistencies in manufacturing or differences in the raw materials used. Even so, both brands generally stayed well below the regulatory limit of 90 ppm, supporting the findings that local paints tend to have lower lead concentrations compared to imported ones, as shown in Figure 9.

4.2 The Results for pXRF and ICP-OES Measurements Mercer University

4.3A The results for lead in legacy paints

To further evaluate the lead content in legacy paint samples, both pXRF and ICP-OES measurements were conducted at Mercer University. The table below presents the lead concentrations obtained from these two analytical methods, allowing for direct comparison of the results.

Table 4. Results of the pXRF and ICP-OES measurements at Mercer University for legacy paints

Legacy Paints		
Sample ID	pXRF (ppm)	ICP-OES (ppm)
NA-Geel SW	61282 ± 650	76801 ± 715
M-Geel SW2	1278 ± 22	1635 ± 7
NF-Geel S	174683 ± 2646	160980 ± 929
NA-Geel HR	86515 ± 1020	114370 ± 486
F-Geel B	1864 ± 21	1901 ± 6
M-Geel S1	251 ± 6	247 ± 6
M-Geel S2	596 ± 13	615 ± 7
F-Geel HR	<LOD	<LOD
F-GeelS W1	<LOD	<LOD
F-Red B	315 ± 13	253 ± 3

A calibration curve was prepared for the ICP-OES measurements to determine the lead concentrations in the paint samples. This curve was created by running a series of standards ranging from 0.1 ppm up to 15 ppm, along with a reagent blank of 2% HNO₃. The resulting regression equation was $y = 5024.55x + 198.30$ with an R² value of 0.9999, indicating a very strong linear relationship between the intensity and the lead concentration. With such a close fit, the calibration curve was used to quantify lead levels in the paint samples analyzed.

Due to complications during international shipping, not all paint samples successfully arrived at Mercer University, and some were damaged in transit. However, enough legacy and new paint

samples were successfully measured to still allow meaningful comparisons and to draw preliminary conclusions about the lead content in these different types of paints. Table 4 only contains the results of the legacy paints, because lead was not detected in any of the new paint samples (see appendix C), and this data will not be used for further comparisons in method. The absence of detectable lead levels in the newly manufactured paint samples is a significant and encouraging outcome. While it is reassuring that lead was not detected in the new paints, it does not exactly mean that it is not present. Any traces of lead that could have been present were too low to be reliably picked up by either method.

4.3B Comparing pXRF measurements completed in Central Lab Suriname vs Mercer University

The pXRF_MU results (Table 4) are shown as whole numbers, because this instrument only displays values without decimals. The pXRF_Sur measurements were completed in duplicate and the pXRF_MU in triplicate, and the average of each was used in the analysis. To see how well the results from the pXRF at the Central Lab in Suriname matched those from Mercer University, a Bland-Altman analysis was done. This method looks at the difference between two measurements and compares it to their average, making it easier to spot any consistent bias or large variations between the two.

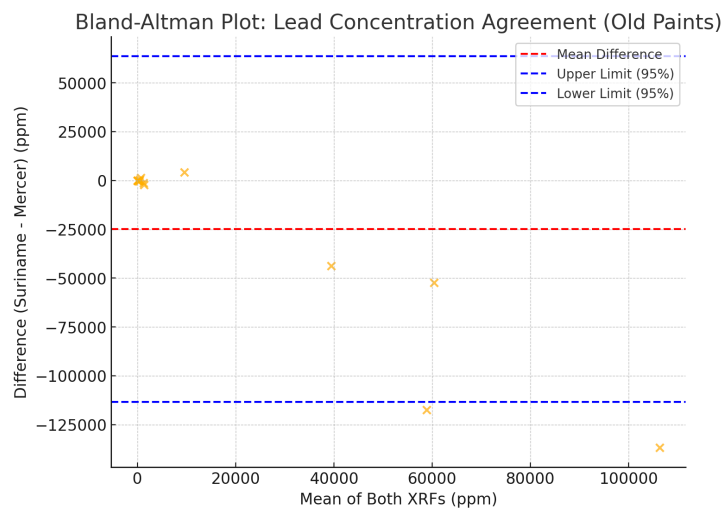


Figure 11. Lead in paint results measured with pXRF_Sur vs pXRF_MU

The boxplot in Figure 11 shows that, on average, the Central Lab reported lead concentrations about 8,495 ppm lower than Mercer. The limits of agreement were wide, ranging from around

–65,834 to +48,844 ppm. The comparison between the pXRF_Sur and pXRF_MU shows a clear positive correlation, which confirms that both sets of measurements generally follow the same trend. However, the values measured by pXRF_Sur tend to be lower than those measured at Mercer. This supports earlier findings and literature showing that individual pXRF instruments may produce slightly different results—even when measuring the same sample under similar conditions. A well-regarded study directly compared multiple pXRF devices and found that measurement differences can be attributed to each instrument’s calibration protocol, electronic signal processing, and operating setting (*Goodale et. al., 2012*). The R^2 value of 0.5675 (see Appendix E) indicates a moderate positive linear relationship between the pXRF_Sur and pXRF_MU. The two pXRF devices give results that are closely related, but do not match exactly.

4.3C Comparison of pXRF_MU vs ICP-OES lead in paint detection

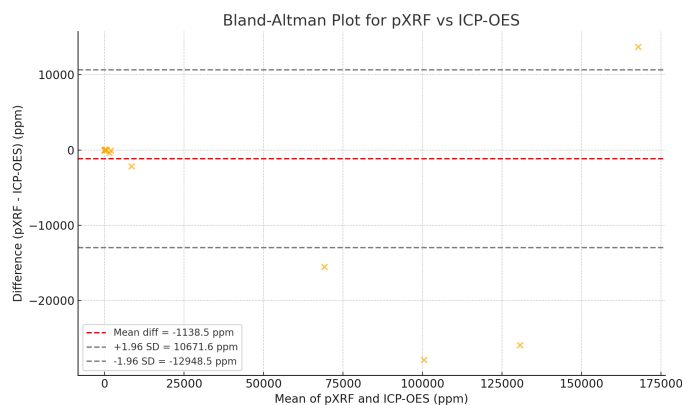


Figure 12. Lead in paint results measured with pXRF vs ICP-OES

To see how well the pXRF_MU measurements matched up with the more precise ICP-OES results, A Bland-Altman analysis was completed, focusing only on samples where at least one of the methods actually detected lead. This analysis showed that, on average, the pXRF readings were about 5,278 ppm lower than the ICP-OES values, pointing to a slight tendency of pXRF to underestimate lead concentrations. This trend aligns with previous research by Seney et al. (2024), who also reported lower readings from pXRF_MU when compared to ICP-based methods (Syney et al., 2024). The differences between the two methods had a standard deviation of roughly 12,550 ppm, with most of the differences falling between –29,876 and +19,319 ppm. This pretty wide range means that even though pXRF_MU and ICP-OES generally showed the same trends across samples, the exact values could differ quite a bit, especially when lead levels

were high. While the pXRF_MU may underestimate lead concentrations compared to ICP-OES, especially at higher levels, this discrepancy does not take away from its effectiveness. Lead levels that reach into the thousands of ppm are already well above the 90 ppm safety limit, making the presence of lead clearly hazardous. So, despite the underestimation, the pXRF still proves to be a reliable tool for detecting dangerously high lead levels during screening.

It is also worth mentioning that for most new paint samples, both methods reported no detectable lead, which shows they were consistent in spotting paints where lead was either not present or below detection limits. Overall, these findings highlight that pXRF works well as a quick screening method, but it is best used alongside more accurate techniques like ICP-OES when exact lead levels are needed.

ICP-OES is known to give really precise results, especially when dealing with very small amounts of a substance. In this study, the practical detection limit for specifically lead in paint using ICP-OES came out to approximately 33.33 ppm, which includes all the steps like digestion and dilution. The pXRF device, according to the manufacturer manual (Seney et al., 2024), has a detection limit of 3 ppm. Even though the pXRF device has a lower listed LOD, that does not automatically mean it's the more sensitive method. With pXRF, the analyzer picks up the fluorescent X-rays coming from the sample and uses the intensity to estimate how much lead is present. But the ICP-OES measures the intensity of the light emitted and then works backwards through calibrated calculations to figure out the exact concentration. Other factors that can contribute to differences are uneven paint surfaces or poor sample mixing with the pXRF. Since ICP-OES analyzes the paint after it has been digested into liquid form, it avoids those surface issues and gives more consistent and reliable results. So, while pXRF gives quick readings, ICP-OES offers a more in-depth and accurate look at how much lead is really in the sample.

4.4 Limitations and Literature Comparison

Even though this research provides meaningful insight into the presence of lead in paints sold in Suriname, there are some limitations that need to be considered. First off, only three paint brands were included in this study, while there are at least seven other local and imported brands available on the market that were not tested. Because of this, the findings cannot be viewed as fully representative of all paints sold in Suriname. Another important factor is the limited

number of samples that were analyzed using both pXRF and ICP-OES. This smaller dataset may have influenced the spread in the Bland-Altman plot and affected the strength of this comparison. Additionally, the measurements were done in different countries—Suriname and the United States—using different equipment, under different lab conditions. These variations can affect the precision and repeatability of the results. Differences in how the samples were prepared—like how well they were mixed or how fine the particles were—could also have influenced the outcomes, especially since pXRF is pretty sensitive to surface details. This kind of variation has also been seen in other research, such as in the study by Seney et al. (2024), where they found that pXRF often underestimated lead levels compared to ICP methods, especially when the concentrations were high.

Chapter 5. Conclusion

This study investigated the concentration of lead in yellow, red, and brown paints currently sold in Suriname and compared these to legacy paints found on playground equipment, using both portable XRF and ICP-OES analysis. The results showed that the legacy red and yellow paint contained significantly higher concentrations of lead, 65% of which exceeded the regulatory limit of 90 ppm. In contrast, no lead was detected in the new paint samples across the same colors and brown. Although the pXRF measurements done in Suriname had limitations in terms of accuracy, they still provided a useful first look and were backed up by more precise ICP-OES analysis. The pXRF tends to underestimate lead concentrations compared to ICP-OES at higher levels; this difference does not really affect the main conclusion. Lead levels in the thousands of ppm are already far beyond the regulatory limit of 90 ppm and clearly pose a serious risk. So, even with this underestimation, the pXRF still works effectively as a screening tool for identifying dangerously high lead concentrations. It also highlights the urgent need for Suriname to establish official guidelines for lead in paint, as well as continued awareness and monitoring efforts to protect public health.

Chapter 6. Recommendations

Given that this study only included a limited number of local and older paint samples, it is recommended that more extensive research be carried out in Suriname to assess lead concentrations in a wider range of paint brands and colors. Additional studies could also focus on testing more public spaces and homes to get a broader view of potential lead exposure risks. This kind of research can provide stronger evidence to support the introduction of regulations or laws specifically aimed at limiting lead in paints sold and used in Suriname, ultimately helping to protect public health, especially that of children. It is also worth mentioning that many of the playgrounds where the legacy paint samples were taken already showed heavy flaking and peeling. Given the high lead levels found in these legacy paints, it would be wise to carefully remove the deteriorating layers and repaint the structures using newer, lead-safe paints to help minimize potential exposure risks.

References

1. Afshari, S., Nagarkar, V., & Squillante, M. R. (1997). Quantitative measurement of lead in paint by XRF analysis without manual substrate correction. *Pergamon*, 48. [https://sci-hub.usualwant.com/10.1016/s0969-8043\(97\)00138-3](https://sci-hub.usualwant.com/10.1016/s0969-8043(97)00138-3)
2. Berman, T., Barnett-Itzhaki, Z., Reicher, S., Ardi, R., Shammai, Y., Aruas, L., & Negev, M. (2018). Lead in spray paint and painted surfaces in playgrounds and public areas in Israel: Results of a pilot study. *Science of the Total Environment*.
3. Bland, J. M., & Altman, D. G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The Lancet*, 327(8476), 307–310. [https://doi.org/10.1016/S0140-6736\(86\)90837-8](https://doi.org/10.1016/S0140-6736(86)90837-8)
4. C. B. Boss and K. J. Fredeen. (1997). Concepts, Instrumentation and Techniques in Inductively Coupled Plasma Optical Emission Spectrometry. *Research Gate* https://www.researchgate.net/figure/The-principle-and-major-components-of-a-typical-ICP-OES-instrument-Boss-and-Fredeen_fig13_268258151
5. Collin, S. M., Venkatraman, S. K., Vijayakumar, N., Kanimozhi, V., Arbaaz, M., & Stacey, S. R. (2022). Bioaccumulation of lead (Pb) and its effects on humans: A review. *Journal of Hazardous Materials Advances*. <https://doi.org/10.1016/j.hazadv.2022.100094>
6. Eckl, A., Paun, M. C., & UNEP Lead Paint Alliance. (2021, April 6). Coloring Our Future Lead-Free. *PCI Magazine*. <https://www.pcimag.com/articles/108604-coloring-our-future-lead-free>
7. Skyray Instruments. (n.d.). *Skyray Explorer 3000 XRF [PDF]* https://www.skyrayinstruments.com/PDF/Skyray_Explorer_3000_XRF_web.pdf
8. Radboud University. (n.d.). *General Instrumentation: Elemental analysis / ICP-OES*. <https://www.ru.nl/science/gi/facilities-activities/elemental-analysis/icp-oes/>
9. Ghosh, S., Prasanna, V. L., Sowjanya, B., Srivani, P., Alagaraja, M., & Banji, D. (2013). Inductively coupled plasma–optical emission spectroscopy: A review. *Asian Journal of Pharmaceutical Analysis*, 3(1), 24–33. https://www.researchgate.net/publication/288811956_Inductively_coupled_plasma_-_Optical_emission_spectroscopy_A_review
10. Goodale, N. G., Bailey, D. G., Jones, G. T., & Lewis, C. (2012). PXRF: A study of inter-instrument performance. *Journal, Volume(Issue), pages*. (Found via ResearchGate – comparing different pXRF units directly.)

11. U.S. Environmental Protection Agency. (n.d.). *Learn about lead*.
<https://www.epa.gov/lead/learn-about-lead>
12. Sandberg. (n.d.). *Lead in paint*.
<https://www.sandberg.co.uk/laboratories/chemistry/lead-in-paint/>
13. Shier, R. (2004). *Statistics: 2.3 The Mann-Whitney U Test [PDF]*. Statstutor.
<https://www.statstutor.ac.uk/resources/uploaded/mannwhitney.pdf>
14. World Health Organization. (2024, September 27). *Lead poisoning and health*.
<https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health>
15. McKnight, P. E., & Najab, J. (2010). Mann-Whitney U test. In I. B. Weiner & W. E. Craighead (Eds.), *The Corsini Encyclopedia of Psychology* (4th ed.). John Wiley & Sons.
<https://doi.org/10.1002/9780470479216.corpsy0524>
16. Milton A. Lessler. (1988). *Lead and Lead Poisoning from Antiquity to Modern Times*. Department of Physiology, Ohio State University, Columbus, OH 43210.
17. National Institute of Standards and Technology. (1994). *Lead-based pigments in paints: Lead chromate, lead molybdate, and others*. U.S. Government Printing Office.
<https://www.govinfo.gov/content/pkg/GOVPUB-C13-2af3d0210c05c7818ca2d7d2304df223/pdf/GOVPUB-C13-2af3d0210c05c7818ca2d7d2304df223.pdf>
18. Ramírez Ortega, D., González Esquivel, D. F., Blanco Ayala, T., Pineda, B., Gómez Manzo, S., Marcial Quino, J., Carrillo Mora, P., & Pérez de la Cruz, V. (2021). *Cognitive impairment induced by lead exposure during lifespan: Mechanisms of lead neurotoxicity*. *Toxics*, 9(2), 23. <https://doi.org/10.3390/toxics9020023>
19. Rumsey, D. J. (2016). *Statistics For Dummies (2nd ed.)*. Hoboken, NJ: John Wiley & Sons.
<https://statistics.laerd.com/statistical-guides/measures-central-tendency-variance.php>
20. Safe Air Fast. (2015, December 9). *A look at the history of lead paint*. *Safe Air Fast Blog*.
<https://www.safeairfast.com/blog/2015/12/a-look-at-the-history-of-lead-paint/>
21. Sellars, S. (2019, June 12). *Overview of Lead Paint Laws in Latin America and the Caribbean*. US Environmental Protection Agency.
<https://www.saicm.org/Portals/12/Documents/GEF-Project/Panama-WS/USEPA-Overview-Regulatory-LAC-EN.pdf>
22. Seney, C. S., Kiefer, A. M., Brown, S. T., Stair, E. R., Nelson, D. G., Bando, L. L., Stewart, B. W., Lara, N. Z., & Donaldson, C. (2024, December 30). *Preliminary studies for the standardization of a pXRF analyzer via ICP-OES for the accurate quantification of*

Pb in new paint. *Royal Society of Chemistry.*
<https://pubs.rsc.org/en/content/articlehtml/2025/ay/d4ay01442a>

23. Turner, A., Kearl, E. R., & Solman, K. R. (2015). Lead and other toxic metals in playground paints from South West England. *Science of the Total Environment*.
24. United Nations Environment Programme. (2020). *Model law and guidance for regulating lead paint.*
<https://www.unep.org/resources/publication/model-law-and-guidance-regulating-lead-paint>
25. United States Consumer Product Safety. (n.d.). *From Lead in Paint.*
<https://www.cpsc.gov/Business--Manufacturing/Business-Education/Lead/Lead-in-Paint#:~:text=If%20you%20have%20a%20product%20subject%20to%20the,the%200.009%20percent%20limit%20%2890%20parts%20per%20million%29>
26. Update on the Global Status of Legal Limits on Lead in Paint September 2018. (2018, September). *United Nations Environment Programme.*
<https://www.saicm.org/Portals/12/Documents/EPI/Lead%20Paint/2018-FINAL-Global-Update-19-OCT-2018.pdf>
27. World Health Organization. (2023, March). *Update on the global status of legal limits on lead in paint* [PDF]
<https://iris.who.int/bitstream/handle/10665/373149/9789240078093-eng.pdf>
28. Völz, & Hans, G. (2000). Pigments, Inorganic. *Ullmann's Encyclopedia of Industrial Chemistry*.
29. What is XRF (X-ray Fluorescence) and How Does it Work? (2020, January 28). *Thermo Fisher Scientific.*
<https://www.thermofisher.com/blog/ask-a-scientist/what-is-xrf-x-ray-fluorescence-and-how-does-it-work/>

Appendix A

Table 5. Results of the pXRF Suriname on new paints samples

New Paint					
Sample ID	Pb Concentration (ppm)	Sample ID	Pb Concentration (ppm)	Sample ID	Pb Concentration (ppm)
H-geel 1	0.12	H-red 1	<LOD	H-brown 1	0.72
H-geel 2	<LOD	H-red 2	<LOD	H-brown 2	0.15
D-geel 2	1.90	D-red 1	0.26	D-brown 1	<LOD
D-red 1	0.26	D-red 2	1.79	D-brown 2	0.15
C-geel 1	0.20	C-red 1	0.33	C-brown 1	<LOD
C-geel 2	1.11	C-red 2	<LOD	C-brown 2	<LOD

Old paints → total sum of ranks = $R_1 = 947.0$

New paints → total sum of ranks = $R_2 = 379.0$

U1 (Legacy paints)

$$U_1 = n_1 \cdot n_2 + \frac{(n_1+1)}{2} - R_1 = 24 \cdot 27 + \frac{24+25}{2} - 947 = 1.0$$

U2 (New paints)

$$U_2 = n_1 \cdot n_2 - U_1 = 648.0 - 1 = 647.0$$

The smaller of U1 and U2 is the Mann-Whitney U statistic: $U = 1.0$

Table 6. Data for Mann-Whitney U-test of legacy vs new lead paints

Group	Count	Mean	Standard Deviation
New	27	0.467	0.769
Old	24	7938.566	12601.962

Appendix B

Table 7. Calculations for Mann-Whitney U-test for local vs imported paints

Group	count	mean	std	min	25%	50%	75%	max
Imported	15	0.50	0.844	0	0	0.02	0.71	2.84
Local	12	0.42	0.69	0	0	0.13	0.37	1.89

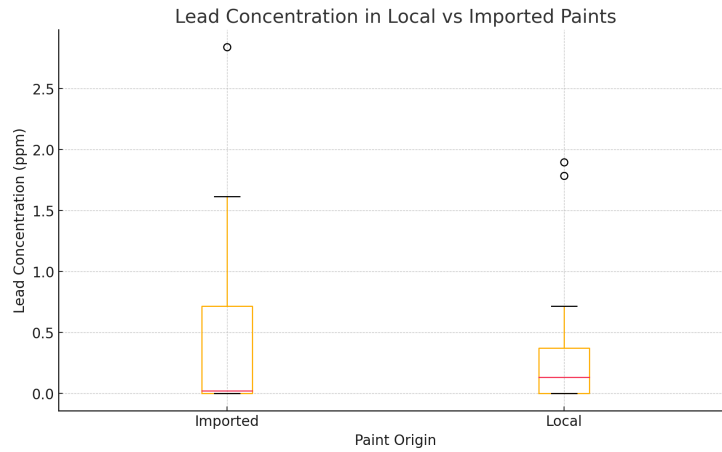


Figure 13. The Mann-Whitney comparison for new paints across larger range of colors

Appendix C

Table 8. Results for new paints with pXRF-MU and ICP-OES

New Paints			
Sample ID	pXRF (ppm)	ICP-OES (ppm)	Standard Deviation (ppm)
H-Geel 1	<LOD	<LOD	2.23
H-Geel 2	<LOD	<LOD	1.71
H-Red 1	<LOD	<LOD	1.17
H-Red 2	<LOD	<LOD	0.96
H-Brown 1	<LOD	<LOD	0.65
D-Geel 1	<LOD	<LOD	0.78
D-Geel 2	<LOD	<LOD	1.07
D-Red 1	<LOD	<LOD	2.18
D-Red 2	<LOD	<LOD	0.36
D-Brown 1	<LOD	<LOD	2.03
D-Brown 2	<LOD	<LOD	1.09
C-Geel 1	<LOD	<LOD	0.92
C-Geel 2	<LOD	<LOD	3.12
C-Red 1	<LOD	<LOD	1.27

C-Red 2	<LOD	<LOD	1.43
C-Brown 1	<LOD	<LOD	0.90
C-Brown 2	<LOD	<LOD	1.58
C-Green 1	<LOD	<LOD	0.29
C-Green 2	<LOD	<LOD	1.41
C-Grey 1	<LOD	<LOD	0.66
C-Grey 2	<LOD	<LOD	1.75
C-Orange	<LOD	<LOD	1.71
C-Turquoise	<LOD	<LOD	0.88
C-White	<LOD	<LOD	1.52
C-Black	<LOD	<LOD	1.31

Calculation of Average Mean Difference : $Mean\ Difference = \frac{1}{n} \sum_{i=1}^n (x1_i - x2_i)$

Mean = (Central Lab value + Mercer value) ÷ 2

Difference = Central Lab value – Mercer value

Then we calculated:

- Mean of all differences = -8,495.22 ppm
- Standard deviation (SD) of differences = ±29,254.71 ppm

Limits of agreement:

- Upper Limit = Mean difference + 1.96 × SD = +48,844 ppm
- Lower Limit = Mean difference – 1.96 × SD = -65,834 ppm

Appendix D

Limit of detection (practical method)

For the practical limit of detection the lowest point in the calibration curve is used.

1. Limit of detection:
0.05(in final solution)
2. Accounting for 1:10 dilution:
 $0.05 \times 10 = 0.5 \text{ ppm}$ (in digestate)
3. Total lead in digestate:
 $0.5\text{mg/L} \times 0.010 \text{ L} = 0.005 \text{ mg Pb}$
4. Concentration in original paint:

$$\frac{0.005 \text{ mg Pb}}{0.00015 \text{ kg Paint}} \approx 33.33 \text{ mg/kg} = 33.33 \text{ ppm} \approx 33 \text{ ppm}$$

This means that under the conditions used in this study, the practical detection limit for lead in the paint samples was approximately 33.33 ppm

Appendix E

To compare the two methods, the results of lead in paint of the pXRF_MU and the pXRF_Sur were plotted against one another and yielded the following plot:

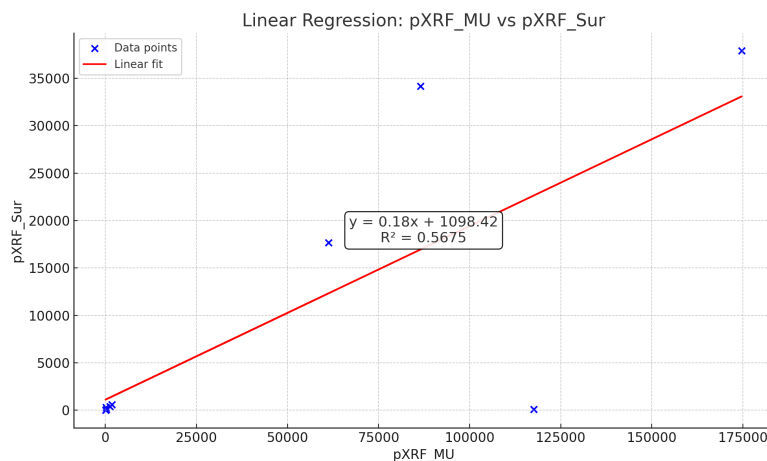


Figure 14 Lead in paint results with pXRF_MU vs pXRF_Sur

To compare the two methods, the results of lead in paint of the pXRF_MU and the ICP-OES were plotted against one another and yielded the following plot:

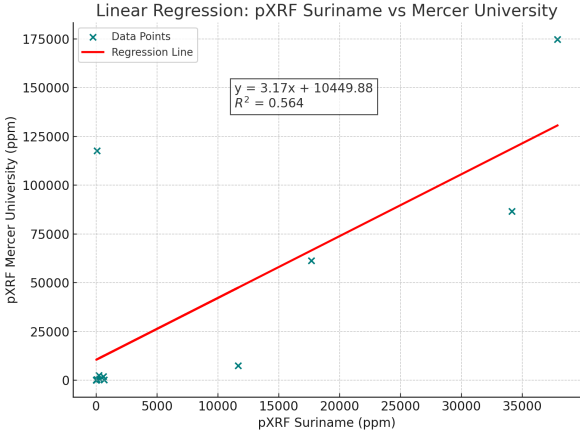


Figure 15 Lead in paint results with pXRF_MU vs ICP-OES