



WALLAGA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

MSc. THESIS

**DETERMINATION OF HEAVY METAL LEVELS (Cr, Pb, Cd,
Zn, Cu AND Mn) IN ONION (*Allium cepa* L.)AND FARM SOIL
FROM LALO ASSABI DISTRICT, WEST WALLAGA ZONE,
ETHIOPIA USING ATOMIC ABSORPTION SPECTROSCOPY**

BY:

YOB SAN BEKELE LIKASA

NOVEMBER, 2025

NEKEMTE, ETHIOPIA



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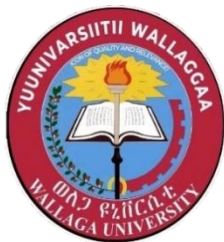
**A THESIS SUBMITTED TO THE COLLEGE OF NATURAL AND
COMPUTATIONAL SCIENCES IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF MASTERS OF INORGANIC
CHEMISTRY.**

BY:

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**NOVEMBER, 2025
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APPROVAL SHEET FOR SUBMITTING FINAL THESIS

As members of the Broad of Examiners of the final M.Sc. thesis open defense, we certify that we have read and evaluated the thesis prepared by Yobsan Bekele Likasa under the title Determination of heavy metal levels (Cr, Pb, Cd, Zn, Cu and mn) in onion (*allium cepa* L.) and farm soil from lalo assabi district, West Wallaga Zone, Ethiopia using Atomic Absorption Spectroscopy” and recommend that the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science by in organic Chemistry.

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I hereby certify that all the correction and recommendation suggested by the broad of examiners are incorporated into the final thesis entitled “Determination of heavy metal levels (Cr, Pb, Cd, Zn, Cu and mn) in onion (*allium cepa* L.) And farm soil from lalo assabi district, West Wallaga Zone, Ethiopia using Atomic Absorption Spectroscopy” by Yobsan Bekele Likasa

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DECLARATION

Heavy Metals in onion and its farm soil in Lalo Assabi district. This is to certify that this thesis entitle title “Determination of heavy metal levels (Cr, Pb, Cd, Zn, Cu and mn) in onion (*allium cepa* L.)And farm soil from lalo assabi district, West Wallaga Zone, Ethiopia using Atomic Absorption Spectroscopy” accepted in the partial fulfillment of the requirement for the award of the degree of masters of sciences by In organic chemistry by the school of graduated studies, Wallaga University through the college of natural and computational science done by Yobsan Bekele Likasa. This thesis has not been submitted earlier for the award of any degree or diploma. The assistance and help received during the course of this examination have been dully acknowledged. Therefore, I recommended that it can be accepted as fulfillment the research thesis requirement of MSc. degree by Inorganic chemistry.

Asnake Lealem (PhD)

Major Advisor

Signature

Date

DEDICATION

This thesis manuscript is dedicated to all my family, for encouraging me with love dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

I declare that this thesis is my work and is not submitted to any institution elsewhere for the award of any academic degree, diploma or certificate and all sources of materials used for thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree at Wallaga University, College of Computational science and is deposited at the University Library to be made available to borrowers under the rules of the library.

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BIOGRAPHICAL SKETCH

The author was born from his father Bekele Likasa Boru and his mother Sukare Biranu Muleta on July 8, 1997 G.C in Haroji Serdo Kebele, Lalo Assabi Woreda, West Wallaga Zone of the Oromia regional Ethiopia. He started his education at Haroji Agemsa (1-8) elementary school and Wallaga Adventist Academy Secondary School (9-10) and completed his senior secondary education at Secondary and Preparatory School in Dongoro town. Upon successful completion of his preparatory school studies, he then joined Haramaya University in September, 2017 and graduated with BSc Degree in Chemistry in July, 2019G.C. He was then assigned by Ethiopian Ministry of Education as secondary school teacher on 2020 to till today at Nole Kaba Woreda. He upgrades the education level recruited by the self-sponsor to join Wallaga University in 2021 G.C in masters of In organic chemistry.

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LIST OF ABBREVIATIONS

AAS	Atomic absorption spectrometry
ANOVA	Analysis of variance
ATSDR	Agency for toxic substance and disease registry
BCF	Bio concentration Factor
CCS	Calibration standards
FAAS	Flame atomic absorption spectrometry
FAO	Food and agriculture organization
ICP-MS	Inductively coupled plasma mass spectrometry
IDL	Instrumental detection limit
LCS	Laboratory control samples
LOQ	Limit of quantification
MDL	Method detection limit
MS	Matric spike
MSD	Matric spike duplicate
Ppm	Part per million
RSD	Relative standard deviation
RSP	Relative percent differences
SD	Standard deviations
SPSS	Statistical package of social sciences
WHO	World health organization

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ABSTRACT

*This study assessed the concentrations of selected heavy metals Chromium (Cr), Lead (Pb), Copper (Cu), Zinc (Zn), Iron (Fe), and Manganese (Mn) in onion bulbs (*Allium cepa* L.) and corresponding farm soils from three sites (Haroji Serdo, Gombo, and Warajiru Bacho) in Lalo Assabi District, West Wallaga Zone, Ethiopia. Soil samples were digested using a tri-acid mixture, and onion samples were processed by dry ashing, followed by analysis using Atomic Absorption Spectrometry (AAS). The mean concentrations in soil followed the order: Cr (42.794 mg/kg) > Zn (18.726 mg/kg) > Pb (8.192 mg/kg) > Cu (3.950 mg/kg) > Fe (1.365 mg/kg) > Mn (0.362 mg/kg). In onion bulbs, alarmingly high levels of Cr (44.936 mg/kg), Pb (7.884 mg/kg), and Cu (7.823 mg/kg) were detected, significantly exceeding international safety standards (FAO/WHO). Bioaccumulation Factor (BCF) values indicated active translocation from soil to plant, particularly for Cu (1.98), Cr (1.05), and Fe (1.63). The findings reveal alarmingly high in both soil and onions, posing substantial (HRI) to consumers through chronic dietary exposure. This study provides critical baseline data and underscores the urgent need for public awareness, routine monitoring, and remediation strategies to ensure food safety in the region.*

Keywords: Bioaccumulation, contamination, Heavy metals.

1. INTRODUCTION

1.1. Background of study

Heavy metals represent a group of metallic elements characterized by a high density, specifically at least five times greater than that of water (Duffus, 2023). This category encompasses both essential and non-essential elements, including cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), and iron (Fe). While some are necessary in trace amounts, these metals become detrimental to human health when they accumulate in bodily tissues at a rate exceeding the body's natural elimination capacity (Islam *et al.*, 2025).

As fundamental components of a healthy diet, vegetables supply crucial carbohydrates, proteins, vitamins, and minerals. However, a significant health risk emerges when these plants are cultivated in soils polluted with heavy metals. The vegetables can absorb these toxic elements and deposit them in their edible portions, creating a pathway for human exposure. The risk is compounded by the body's limited ability to excrete these persistent contaminants. The degree to which a plant absorbs metals depends on factors such as the metal's chemical form in the soil, the soil's properties, and the specific plant species (Bhuiyan *et al.*, 2023).

The issue of environmental contamination is escalating worldwide, with developing nations experiencing acute challenges due to rapid industrial and urban expansion. The inherent persistence, non-biodegradability, and bio-accumulative potential of heavy metals render their presence in the agricultural food chain a serious public health concern (Alengebawiy *et al.*, 2023).

Despite the widespread consumption of onion in Ethiopia and the known pathways for heavy metal contamination in vegetables, a significant research gap exists regarding the safety of onions specifically cultivated in the Lalo Assabi district. While studies have been conducted in other regions of Ethiopia, such as the Central Rift Valley, there is a complete absence of published data on the levels of both essential and toxic heavy metals in the onion-soil system of this distinct agricultural zone. To address this gap, the present study was designed to quantify the concentrations of Copper (Cu), Chromium (Cr), Iron (Fe), Manganese (Mn),

Zinc (Zn), and Lead (Pb) in onion bulbs and their corresponding farm soils from three selected sites in Lalo Assabi. Atomic Absorption Spectrometry (AAS) was selected as the analytical technique due to its well-established reliability, accessibility, cost-effectiveness, and sufficient sensitivity for the determination of these metals in environmental samples. Soil samples were digested using a tri-acid mixture; while onion samples were undergo dry ashing, followed by analysis with AAS. Ultimately, this research was aims to determine the contamination status, assess potential health implications, and provide scientifically sound data to inform agricultural practices and public health guidance in the region. (Alum *et al.*,2024).

1.2. Statement of the problems

Existing research on heavy metals in Ethiopian onions is limited, with sporadic studies available from regions like the Central Rift Valley (Fekadu Demsie *et al.*, 2023). A critical knowledge gap exists for the Lalo Assabi district. The agricultural soils in this region may be subject to contamination from various sources, including fertilizers, pesticides, and organic manures. Consequently, onions cultivated in these soils have the potential to accumulate hazardous levels of metals such as Copper, Chromium, and Lead. This accumulation poses a direct and significant health threat to consumers who regularly incorporate onions into their diets. This study was therefore conceived to address this gap by generating the first comprehensive dataset on the concentrations of selected heavy metals in both onion bulbs and their corresponding cultivated land within the Lalo Assabi district.

1.3. Research Gap

A comprehensive review of existing literature reveals that no prior study has been conducted to determination of heavy metal levels (Cr, Pb, Cd, Zn, Cu and mn) in onion (*allium cepa* L.)And farm soil from lalo assabi district, West Wallaga Zone, Ethiopia using Atomic Absorption Spectroscopy.. This study seeks to fill this critical knowledge gap by providing the first systematic assessment of selected heavy metals in the onion (*Allium cepa* L.) and soil samples of these specific kebele.

1.4. Objectives

1.4.1. General Objectives

- To determine selected heavy metal levels (Cr, Pb, Cd, Zn, Cu and mn) in onion (*allium cepa* L.) And farm soil from lalo assabi district, West Wallaga Zone, Ethiopia using Atomic Absorption Spectroscopy.

1.4.2. Specific Objectives

- ❖ To determine the concentrations of (Cu, Cr, Fe, Mn, Zn and Pb) in cultivated land samples from onion farm in Lalo Assabi district study areas using AAS
- ❖ To determine the concentrations of (Cu, Cr, Fe, Mn, Zn and Pb) in onion samples of the Lalo Assabi district study area using AAS.
- ❖ To Compare with international standard .

1.5. Significance of the study

The onion is a ubiquitous food additive consumed extensively by urban and rural populations across Ethiopia. This study provides vital information regarding the composition of this widely consumed onion, specifically its content of essential and non-essential metals. Assessing the levels of these metals in onions and their growth medium is critical for evaluating potential consumer exposure and associated health risks. The findings will serve to raise public awareness, contribute to ensuring dietary safety, and offer a scientific foundation for advocating for sustainable and safe onion production practices. Furthermore, the results of this investigation will establish a crucial baseline for future research and may inform the development of targeted soil remediation strategies.

2. LITERATURE REVIEW

2.1. Heavy metals in the environment

The introduction of heavy metals into ecosystems occurs through a combination of natural processes, such as the weathering of geological formations, and human activities, including mining, industrial effluent discharge, and agricultural practices (Rahmatpour *et al.*, 2021). These metals pose a considerable and long-term threat to the environment due to their inability to degrade, their persistence in soils, and their tendency to bio-accumulate within food webs, ultimately posing risks to human and animal health (Fordham *et al.*, 2021).

The concentration of heavy metals found within crops is not uniform it is heavily influenced by the plant species' genetics and the bioavailability of the metal in the soil, which is in turn governed by local soil physicochemical conditions (De Langen *et al.*, 2023). At elevated concentrations, these metals can interfere with essential plant physiological processes, including photosynthesis and respiration. Although roots typically accumulate higher metal concentrations than aerial parts, the translocation of even small amounts to the edible portions is a primary focus for food safety (Mandangu *et al.*, 2023). Long-term dietary intake of toxic metals like Chromium and Lead is associated with severe systemic health problems in humans (Mansour *et al.*, 2023). Serious systemic health hazards can develop as a result of extreme dietary accumulation of heavy metals such as Cr, Cd, Ni and Pb. Plants and animals take up metals from contaminated soil and water as well as from deposits on parts of the plants exposed to the air from polluted environment. (Ghanbari Mohazzab *et al.*, 2023).

2.2. Sources of heavy metals

Natural and anthropogenic sources of soil contamination are widespread and variable. Heavy metals occur naturally in rocks. Mineral rock weathering and anthropogenic sources provide two of the main types of metal inputs to soils. In localized mineral zones or around volcanoes an elevated level of the elements arsenic, lead, cadmium, copper and zinc can also be found. Cadmium is associated with sphalerite, and lead is found in many ores. Anthropogenic activities, such as mining, industrial effluents, floriculture, application of fertilizer, pesticide, Bio solids, manures and sewage sludge application. (Gedik *et al.*, 2023).

This sources increases heavy metal concentrations in the soil and considered to pose possibly serious hazards in the soil-plant-animal system are discussed here. (Dai *et al.*, 2023).

2.2.1. Fertilizers

Fertilizers are used in many different forms of agriculture to increase the level of crop production by adding nutrients to the soil that benefit the growth of plants. However, they are often harmful to the environment. Fertilizer use can have negative health implications. The excessive use of nitrates has been linked to the blood disorder methemoglobinemia, commonly known as blue baby syndrome, which occurs when people drink water that is contaminated with excess nitrates. Excess nitrates interfere with the oxygen carrying capacity of the blood, and have also been suspected as a carcinogen (Schwarz *et al.*, 2023).

2.2.2. Pesticides

Numerous known insecticides used widely in agriculture in the past contained considerable amounts of metals. As in the recent past, near 10% of the chemicals have permitted for use as pesticides and in UK fungicides were based on complexes which comprise. (Cu,Cr,Fe, Pb, Mn or Zn). For Example, such pesticides that are fungicidal spray that contained copper like copper ox chloride and Bordeaux mixture that consists of copper sulphate. Lead arsenate was applied in fruit orchards for several years to regulate some parasitic pests. Compounds that consist of arsenic were applied widely to control livestock ticks and for the control of insects in banana in New Zealand and Australia, wood has been well-preserved with preparations of Copper, Chromium and Arsenic, and there are currently many neglected sites where soil amounts of these elements largely surpass background focuses. Such pollution has the capacity to result in problems, especially if sites are improved for other agricultural or non-agricultural purposes. Linked with fertilizers, the application of these ingredients has been more restricted, being localized to special sites or crops. (Zhu *et al.*, 2024).

2.2.3. Bio solids and Manures

The supply of various bio-solid for example. composts, cattle's manure and municipal sewage sludge to land unconsciously points towards the build-up of heavy metals like Arsenic, Cadmium, Chromium, Copper, Lead as well as Hg, Se, Ni, Mo, Zn, Sb, in the soil.

Some animal wastes like livestock, poultry and pig manures created in agriculture are usually supplied to crops and meadows either in the form of solids or semi solids. Though most compost can be seen as valued fertilizers, in the poultry and pig industry, the Copper and Zinc are included in foods as growth enhancers and Arsenic presence in poultry fitness products may have the ability to cause metal pollution of the soil. The manures that are created from animals as a result of these diets possess greater amounts of Cu, As and Zn and, if continually supplied to prohibited areas of land, can result in reasonable accumulation of these metals in the longer period of time in these soils (Ebrahimi *et al.*, 2023).

Heavy metals most usually 7 established in bio solids include Ni, Pb, Cd, Cu, Cr and Zn, and the metal amounts are ruled by nature and the strength of the industrial processes, as well as the sort of activity worked during the treatment of bio solids. Under specific situations, metals supplied to soils by applying bio solids can be percolated downwards by the soil horizons and may have the ability to pollute groundwater. Latest researches on some soils of New Zealand applied with bio solids have resulted in increased amounts of Ni, Cd and Zn in drainage percolates (Suoranta *et al.*, 2023).

2.2.4. Wastewater

Effluent as a carrier or living environment for a number of pathogenic micro-organisms, such as bacteria, viruses and parasites, is one of the greatest threats to food safety. Water use in crop production involves numerous field operations, including irrigation and application of pesticides and fertilizers. Water of inadequate quality has the potential to be a direct source of contamination as well as a vehicle for spreading localized contamination in the field and in facilities used for postharvest processes (Lobo *et al.*, 2023).

2.2.4.1. Industrial wastes

Extra materials are produced by a variation of industries such as tanning, sugar, textile, petrochemicals from unintentional oil spills or consumption of petroleum-based products, insecticides and pharmaceutical industries and are extremely variable in configuration. Although certain products are disposed of on soil, some have assistances for agriculture and forestry.

In addition, various are possibly dangerous due to their constituents of heavy metals like Cr, Pb and Zn or poisonous organic mixtures and are sometimes, if ever, supplied to land. Some others are actually little in plant nutrients or have no soil conditioning effects (Sumner *et al.*, 2024).

2.2.4.2. Chemical hazards

Chemical substances were posing a serious health hazard to the consumer if they contaminate fresh fruit and vegetables in significant concentrations. Contamination may be caused by either 8 naturally occurring substances or by synthetic chemicals that may be added or are present during agricultural production or post-harvest treatment and further processing. The presence of high concentrations of cadmium, chromium, copper, mercury, nickel and zinc in vegetables give evidence of industrial pollution in agricultural fields. Long-term exposure to low levels of these chemical pollutants can lead to chronic health effects and enhance the risk of adverse pregnancy outcomes. Empirical evidence shows a strong association between drinking water pollution and cancer incidence and mortality. In addition to this, it has been known that intake of food which contains high levels of heavy metals for a long time, poses risks to human health (Chahal *et al.*, 2024).

2.2.5. Floriculture

Due to the rapid growth of the floriculture industry, many have become concerned by the potential for adverse environmental impacts. Fertilizers and pesticides, used extensively in the industry, have been linked to negative environmental and health impacts. Floriculture companies often build greenhouses along lake sides to facilitate easy irrigation systems for their flowers, which threaten the availability and quality of these water resources. In the floriculture industry, fertilizer demand is especially high due to the year-round production of flowers. (van der Aalst *et al.*, 2023).

2.3. Analytical Techniques for analysis of metals in plants, soils and waters samples

Many instrumental analytical methods may be employed to measure the concentration level of heavy metals in various samples. The most predominant techniques are atomic absorption spectrometry (AAS) or inductively coupled plasma mass spectrometry (ICP-MS) is the most widely used technique because for the analysis of trace metals at mg/L concentration levels with good precision for many elements in food samples, soil and water. The main advantages of above instruments are low in cost or cheaper than the others and their disadvantage is not found in our country. Furthermore, AAS is cheap and its usage easier than other instruments (Khan *et al.*, 2023).

2.4. Sample decomposition techniques

Many analytical methods including Atomic Absorption Spectrometry for trace element determination in plant materials require the digestion of the sample. Because of its sensitivity, specificity, simplicity and precision, Atomic Absorption Spectrometry (AAS) is the most widely recommended instrument utilized in analytical procedures for trace heavy metal analysis. In order to separate the analyte from the matrix and to avoid organic matters which may react with the metal ions or chemical reagents and interfere with the analyte in acid digestion methods are very important step. The most commonly used methods for the sample treatment of spices are dry ashing, wet ashing and microwave assisted treatment (Majewski *et al.*, 2023).

Dry ashing: procedures use a high temperature muffle furnace capable of maintaining temperatures of between 200 and 600°C. Water and other volatile materials are vaporized and organic substances are burned in the presence of oxygen in air to CO₂, H₂O and N₂. Most minerals are converted to oxides, sulfates, phosphates, chlorides or silicates. The advantage of Dry ashing is safe, few reagents are required, many samples can be analyzed simultaneously and not labor intensive. The disadvantage of this method is, it requires relatively expensive apparatus (platinum crucibles and muffle furnace) and there is danger of

volatilization of significant amounts of some electrolytes when the digestion temperature is kept high enough to yield a white ash (Altunay *et al.*, 2024).

Wet ashing: is primarily used in the preparation of samples for subsequent analysis of specific minerals. It breaks down and removes the organic matrix surrounding the minerals so that they are left in an aqueous solution. A dried ground food sample is usually weighed into a flask containing strong acids and oxidizing agents (e.g. Nitric, per chloric and/or sulfuric acids) and then heated. Heating is continued until the organic matter is completely digested, leaving only the mineral oxides in solution. The temperature and time used depends on the type of acids and oxidizing agents used. Typically, a digestion takes from 10 minutes to a few hours at temperatures of about 350°C. The advantage of this method is little loss of volatile minerals occurs because of the lower temperatures used, more rapid than dry ashing.

The disadvantages of this method are, it is labor intensive, requires a special fume-cupboard if per chloric acid is used because of its hazardous nature, and low sample throughput (Jankowski *et al.*, 2020).

Microwaves: are non-ionizing electromagnetic radiations. Molecules exposed to microwave radiation undergo molecular motion by the migration of ions and the rotation of dipoles without changing the structure. The advantages Microwave digestion over more traditional procedures: a shorter acid digestion time; a supposed better recovery of volatile elements; lower contamination levels; minimal volumes of reagents are required, more reproducible procedures; and a better working environment. It has also its own disadvantage: the microwave itself is expensive and overall analysis time is not much longer. This is due to the sample vessel handling. Opening and closing of the sample vessel is a step that is not necessary using glass beakers with the hot plate digestion (Maronić *et al.*, 2024).

2.5. Effects of Heavy Metals on Human Health

Heavy Metal	Source/Use in Soil & Onion	Beneficial Role in Humans	Toxic/Health Effects (Excess or Contamination)
Copper (Cu)	Present naturally in soil; absorbed by onions; used in fungicides and fertilizers	Essential trace element; supports enzyme activity, iron metabolism, connective tissue formation	Excess causes liver/kidney damage, gastrointestinal distress, neurological disorders
Chromium (Cr)	Found in soil from industrial waste, leather tanning, fertilizers; onions can accumulate	Cr ³⁺ helps regulate blood sugar and insulin action	Cr ⁶⁺ is toxic: causes skin irritation, respiratory problems, lung cancer
Iron (Fe)	Common in soil; onions absorb Fe; fertilizers may add iron	Vital for hemoglobin, oxygen transport, enzyme activity	Overload leads to hemochromatosis, liver cirrhosis, diabetes, heart disease
Manganese (Mn)	Present in soil; onions uptake Mn; used in steel alloys, fertilizers	Cofactor for enzymes in metabolism, bone formation, antioxidant defense	Excess causes neurological issues (manganism), tremors, memory loss, Parkinson-like symptoms
Zinc (Zn)	Soil enriched by fertilizers, pesticides; onions accumulate Zn	Essential for immune function, wound healing, growth, enzyme activity	Excess causes nausea, vomiting, immune dysfunction, copper deficiency
Lead (Pb)	Soil contamination from industrial pollution, old pipes, paints; onions can absorb Pb	No beneficial role in humans	Highly toxic: damages nervous system, kidneys, reproductive system; causes anemia, developmental delays in children

Table 1. Uses And Health Effects Of Selected Heavy Metals (Cu, Cr, Fe, Mn, Zn, Pb) In Soil, Onion, And Humans.

3. MATERIALS AND METHODS

3.1. Description of the study area

This research was conducted in Lalo Assabi District, one of the districts within the West Wallaga Zone of the Oromia Regional State in Ethiopia. The district's capital town, also named Lalo Assabi, is located approximately 442 kilometers west of Addis Ababa. Lalo Asabi is bordered on the south by Yubdo, on the west by Ayra Guliso, on the north by Boji, on the east by the Benishangul-Gumuz Region, and on the southeast by Gimbi. The area is characterized by a temperate climate, classified as "Weina Dega," with an average annual temperature of 24.5°C and substantial mean annual rainfall of 1,737.5 mm. The topography is varied, with altitudes ranging from 2,215 to 3,178 meters above sea level. Its Lalo Assabi District is situated at 35.8333W longitudes and 9.0833 S latitude.

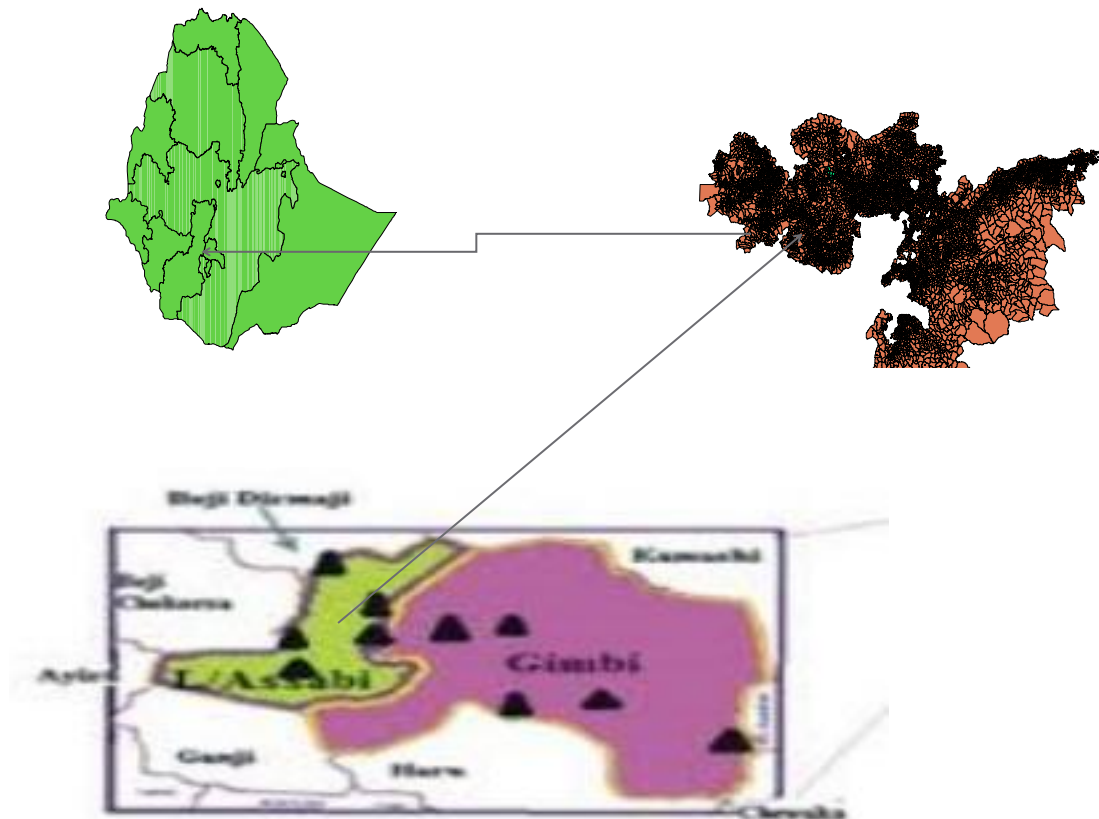


Figure 1: Map of the study area.

3.2. Experimental site

The experimental work was conducted in chemistry laboratory and the analysis of heavy metals was performed using AAS (Jena zeenit 700p model, Germany) at Addis Ababa University, Oromia, Ethiopia. These areas were vast and were characterized by the presence of many pesticide users. Each site was approximately one hectare in size and had been cultivated for over 20 years.

3.3. Apparatus and instrument

The experimental work utilized a range of laboratory apparatus and instruments. Sample preparation involved a chopping board, a Teflon knife, an air-circulating oven, and porcelain mortars and pestles. An analytical balance was used for precise weighing. A muffle furnace was employed for the dry ashing of onion samples, and a block digester system with reflux condensers was used for soil digestion. The final quantification of metal concentrations was performed using an Atomic Absorption Spectrophotometer (AAS) equipped with a deuterium background corrector and specific hollow cathode lamps for each metal.

3.4. Chemicals and reagents

All chemicals and reagents used in this study were of analytical grade to ensure accuracy and minimize contamination. High-purity nitric acid (HNO_3), sulfuric acid (H_2SO_4), and hydrochloric acid (HCl) were used in the digestion procedures. Certified stock standard solutions of each metal (1000 mg/L) were procured and used to prepare intermediate and working standard solutions through serial dilution. Throughout the experiment, distilled water was used for all dilutions, and for rinsing glassware and sample containers.

3.5. Sample collection and preparations

All Nine samples of soil and onion samples each of them three composite was collected using zigzag sampling technique. (Demir *et al.*,2024). from Haroji Serdo, Warajiru Bacho ,Gombo farmlands.

3.5.1. Soil sample collection and preparation

Soil samples were collected from the top layer (20 cm depth) of onion farms using a soil auger (Hicks Pries *et al.*,2023).. The sampling was conducted across three selected farmlands: Haroji Serdo, Warajiru Bacho, and Gombo. A zigzag sampling pattern was followed to obtain a representative composite sample from each location. From each main site, three separate composite samples, each weighing approximately 1 kg, were obtained. In the laboratory, the samples were air-dried, thoroughly ground using a mortar and pestle, passed through a 2 mm sieve to remove coarse debris, and stored in sealed containers at ambient temperature prior to analysis.

3.5.2 Onion sample collection and preparation

Fresh onion bulbs were harvested concurrently with the soil sampling from the same farm locations. Three composite samples, each weighing 1 kg bring to laboratory, were procured directly from farmers' fields in each of the three study areas. Upon transport to the laboratory, the onions were meticulously washed first with tap water to remove adhered soil and particulate matter, followed by a final rinse with distilled water. The cleaned samples were then oven-dried at 70°C for 24 hours until a constant weight was achieved. The dried material was ground into a homogeneous fine powder using a mortar and pestle and stored for subsequent digestion.

3.6. Digestion of samples

3.6.1. Digestion of Soil Samples (Tri-Acid Mixture Method)

Optimized Digestion Procedures

The digestion of soil samples was performed using an optimized wet ashing method with a tri-acid mixture, as referenced from (Hussain *et al.*,2024). The procedure was carefully controlled to ensure complete oxidation of organic matter and dissolution of heavy metals.

Optimized Acid Ratio: The final optimized volume ratio of the acids was HNO₃: H₂SO₄: HCl = **5: 1: 1**.

Steps Followed:

Weighing: 1.0 gram of the dried, sieved (2 mm) soil sample was accurately weighed into a clean, dry digestion tube. **Initial Acid Addition:** 10 mL of concentrated Nitric Acid (HNO_3) was carefully added to the sample. The mixture was gently swirled to ensure that all soil particles were wetted. The sample was allowed to stand for 10–15 minutes to initiate the reaction with organic matter.

Primary Digestion: The tube was placed on a pre-heated block digester and heated at 85°C for 45 minutes. During this step, the bulk of the organic material was oxidized by the nitric acid. The solution was typically observed to turn brown or yellow. **Secondary Acid Addition:** After cooling slightly, 2 mL of concentrated Sulfuric Acid (H_2SO_4) was carefully added. The mixture became hotter and was gently swirled.

Tertiary Acid Addition: Next, 2 mL of concentrated Hydrochloric Acid (HCl) was carefully added. The HCl was used to dissolve oxides and silicate matrices. **Main Digestion:** The block digester temperature was increased to 150°C and the sample was refluxed for approximately 2 hours. Heating was continued until dense, white fumes of SO_3 appeared and the solution became clear and transparent, indicating complete digestion. If the solution remained brown or cloudy, an additional 2 mL of HNO_3 was added and heating was continued until the solution became clear.

Cooling and Filtration: The tube was removed from the digester and allowed to cool to room temperature. The digestate was carefully diluted with a small amount of distilled water and filtered through Whatman No. 42 filter paper into a 50 mL volumetric flask to remove insoluble silicates or residues.

Dilution to Volume: The digestion tube and filter paper were rinsed several times with small portions of distilled water, with all washings collected in the volumetric flask. The volume was finally made up to the 50 mL mark with distilled water and mixed thoroughly. The sample was then ready for AAS analysis.

3.6.2. Digestion of Onion Samples (Dry Ashing Method)

The digestion of onion samples was carried out using an optimized dry ashing procedure, as described by Sayem *et al.*,(2003). This method effectively destroys the organic matrix, leaving the metals in an inorganic soluble form.

Optimized Ashing and Dissolution Ratio: The optimized protocol uses a sample-to-acid ratio where the result was white ash and it is dissolved in a minimal amount of acid. The effective ratio is the dissolution of the ash from 1 gram of dried onion powder in 2.5 mL of concentrated HCl, made up to a final volume of 100 mL.

Steps Followed

Weighing: 2.0 grams of the finely ground, oven-dried onion powder were accurately weighed into a pre-cleaned, pre-weighed porcelain crucible. **Charring:** The crucible was placed on a hot plate in a fume hood and gradually heated until the sample stopped smoking. This initial charring step was carried out to prevent violent ignition in the furnace.

Ashing: The charred crucible was transferred to a cool muffle furnace. The temperature was gradually increased to 550°C over 2 hours to prevent sample loss from spattering. This temperature was maintained for 6 hours to ensure complete ashing, resulting in a white or greyish-white residue. **Cooling:** The furnace was turned off and the crucible was allowed to cool inside the furnace to near room temperature to prevent thermal shock. The crucible was then transferred to a desiccator for complete cooling.

Acid Dissolution: The cool ash was moistened with a few drops of distilled water. 5 mL of concentrated Hydrochloric Acid (HCl) was carefully added down the sides of the crucible. The acid volume was calculated based on the initial sample weight (2.5 mL HCl per 1 g of sample). **Heating and Transfer:** The crucible was gently heated on a hot plate at 80°C to complete the dissolution of the ash. A clear solution was obtained. **Filtration and Dilution:** The solution was filtered through Whatman No. 41 filter paper into a 100 mL volumetric flask. The crucible and filter paper were thoroughly rinsed with distilled water.

Final Volume: The final volume was made up to the 100 mL mark with distilled water and mixed well. The sample solution was then ready for analysis by AAS.

Sample Type	Method	Key parameter	Optimized value/ratio
Soil	Wet Ashing	Tri-Acid Mixture	HNO ₃ : H ₂ SO ₄ : HCl=5.1.1 (by volume)
Onion	Dry Ashing	Ashing temperature/time	550°C for 6 hour
		Acid dissolution	Ash from 1g sample + 2.5 mL coc. HCl (final vol. 100mL)

Table 2. Digestion of samples.

By following these optimized and detailed steps, the digestion procedures was robust, reproducible, and ensure complete extraction of the target heavy metals for accurate quantification.

3.7. Quality control and method validation for metal analysis

In order to validate the analytical method, the following method validation parameters such analysis and determination of continuous calibration standard, limit of detection, limit of quantification, precision and accuracy studies through the analysis of method blank, laboratory control sample, matrix spike and matrix spike duplicate analyses was carried out.

3.7.1. Instrumental calibration

The AAS instrument was calibrated prior to sample analysis using a blank and a series of at least four working standard solutions of known concentrations, prepared by diluting intermediate stock standards (Rai *et al.*, 2023). Calibration curves were plot with different points for each of these metals standard using absorbance against concentrations (mg/L). Immediately after calibration using the standard solutions, the sample solutions was aspirate into the AAS instrument and direct reading of the metal concentrations was recorded. (Stafoggia *et al.*, 2023).

3.7.2. Analytical method validation

Recovery is one of the most commonly used techniques utilized for validation of the analytical results and evaluating how far the method is acceptable for its intended purpose. Because of the absence of certified reference material for the onion and their soil samples; validity of the digestion procedures was assured by spiking the samples with a standard solution of known concentration of the target analyte. The spiking the pre-treated two sub-samples of vegetable and soil samples be digested in the same procedure used for digestion of the vegetables and the soil samples. The resulting digest of the spiked samples was analyzed for their respective metal contents using AAS and percent recoveries was calculated for the vegetables and the soil samples in triplicates. (Arteaga *et al.*, 2022).

3.7.2.1. Accuracy

The accuracy of the entire analytical procedure, from digestion to instrumental analysis, was evaluated through a spike recovery study. Known concentrations of standard solutions were added to duplicate sub-samples prior to digestion. The percentage recovery was calculated, with acceptable performance defined as recoveries falling within the range of 80% to 120% (Javed *et al.*, 2010).

$$\% \text{ Recovery} = \frac{\text{conc in spiked sample} - \text{conc in unspiked sample}}{\text{added amount}} \times 100 \dots \dots \dots (1)$$

3.7.2.2. Precision

The precision of the method, indicating the reproducibility of results, was expressed as the Relative Standard Deviation (RSD) of triplicate analyses. An RSD value of $\leq 15\%$ was considered acceptable for this study (Skoog *et al.*, 2022).

The relative standard deviation (RSD) of the samples was obtained as:

$$\% \text{RSD} = \frac{\text{standard deviation}}{\text{mean}} \times 100 \dots \dots \dots (2)$$

3.7.3. Method detection limit (MDL) and Limit of quantification (LOQ)

The sensitivity of the method was determined by processing multiple reagent blanks through the entire analytical procedure. The MDL was calculated as the standard deviation of the blank responses multiplied by the appropriate student's t-value at a 99% confidence level. The LOQ, defined as the lowest concentration that could be quantified with acceptable certainty, was established as ten times the standard deviation of the blank. (Lambarki *et al.*,2025).

$LOD = 3X S_b$: Where, S_b is standard deviation of the method blanks

$LOQ = 10 X S_b$: Where, S_b is the standard deviation of the method blank

3.7.4. Contamination control

Procedural blanks (method blanks) were processed simultaneously with each batch of samples to monitor and correct for any potential contamination introduced from reagents, glassware, or the laboratory environment. (Das *et al.*,2024).

3.7.4.1 Blanks

A blank was used to assess the degree of contamination in any step of the measurement process. They was also be used to correct relatively constant, unavoidable contamination. Blanks was samples that do not contain any or a negligible amount of analyte. They were made to simulate the sample matrix as closely as possible. (Schloss *et al.*,2024).

3.7.4.2. Method Blank

A method blank was carried through all the steps of sample preparation and analysis as if it is an actual sample. This was the most important from the sample preparation prospective. The method blank accounts for contamination that may occur during sample preparation and analysis. These could arise from the reagents, the glassware, or the laboratory environment. For the method blank known concentration of soil i.e. control sample is used as a matrix and prepared using the same digestion procedure described for the soil samples but with no added sample.

The analysis result revealed that there was no reading above the method detection limits of the metals. Hence, it was concluded that the analytical method was free of overall laboratory contamination (Mitra *et al.*, 2024).

3.7.4.3. Analysis of matrix spike and matrix spike duplicate

Matrix spike (MS) and matrix spike duplicate (MSD) samples are two aliquots of the same environmental sample to which known quantities of the method analyte was added in the laboratory. Both MS and MSD were prepared by spiking of each soil samples with a mixture of spiking standards. They were all carried through the same digestion and analysis steps as the unspiked sample.

The relative percent differences (RPD) between the MS and MSD results will be calculated using the following equation (Kan *et al.*, 2024)

$$RPD = \frac{\text{MS sample result} - \text{MSD sample result}}{\frac{\text{MS sample result} + \text{MSD sample result}}{2}} \dots\dots\dots (3).$$

The relative percent difference (RPD) values were in the acceptable limits $\leq 10\%$.

3.7.4.4. Laboratory control samples (LCS)

For the soil sample, three replicates of sucrose (method blank) spiked with a mixture of standards and digested like the sample including exposure to all glassware, digestion media, apparatus, solvents, and reagents that was used with soil samples. The values was found under the recommended control limits 80–120% for LCS recovery (Hussain *et al.*, 2024). The percent LCS recoveries for each metal was calculated using the following equation. (Haq *et al.*, 2023).

$$\% R = \frac{LCS}{S} \times 100$$

Where: %R = percent recovery, LCS = Laboratory Control Sample Result, S = amount of spike added.

3.8. Analysis of samples

Concentrations of Copper, Chromium, Iron, manganese, Zinc and lead in the filtrate of digested soil and onion samples was estimated by using an Atomic Absorption Spectrophotometer. The instrument was fitted with specific lamp of particular metal. Working standard solutions of copper (Cu), Zinc (Zn), manganese (Mn), Iron(Fe), chromium (Cr) and lead (Pb) was prepared from the stock standard solutions containing 1000 mg/L of element in 2N HNO₃. The instrument was calibrated with calibration blank and five series of calibration standard solutions, these solutions was diluted for desired concentrations to calibrate the instrument. Air-acetylene as fuel-oxidant mixture was used as the fuel and air as the support.

3.8.1. Data analysis

All the results of analysis were reported as mean $\pm$ standard deviation of triplicate measurements. The data was computed using Statistical Package for Social Science (SPSS) statistic 10.0 (Microsoft window) for heavy metal analysis. The recorded data was subjected to analysis of variance (ANOVA), to assess the effect of vegetable type and site of production on the concentrations of heavy metal contaminant in the vegetables and soil tested. As the level of heavy metal contamination might vary with sample collection site and vegetable type, one way ANOVA was used to test the existence of significant difference between means. In all statistical analyses, confidence level was held at 95%.

4. RESULTS AND DISCUSION

4.1. Concentration of Heavy Metals in Soil Samples

The mean concentrations of the heavy metals in the soil samples from the three farmlands are summarized in Table 3. The results are expressed in mg/kg on a dry weight basis.

Metal	Haroji Serdo (H)	Gombo (S)	Warajiru Bacho (T)	Mean $\pm$ SD	FAO/WHO
Mn	0.534	0.190	ND	0.362 ± 0.470	Not limited
Zn	18.909	18.437	18.832	18.726 ± 0.256	50-60
Pb	7.167	7.500	9.910	8.192 ± 1.423	0.3
Cu	1.133	0.800	9.917	3.950 ± 5.049	5.0
Cr	42.286	41.857	44.238	42.794 ± 1.195	1.0
Fe	0.346	1.892	1.856	1.365 ± 0.850	Not limited

Table 3. Mean concentration (mg/kg) of heavy metals in soil samples (n=3 per site).

Note: A negative value for Mn in the T-series indicates a concentration below the method's detection limit or a calibration artifact; it is treated as a non-detect for the mean calculation. The analysis revealed a varied accumulation of heavy metals in the soil. Chromium (Cr) was found to be the most prevalent metal, with a mean concentration of 42.794 mg/kg, followed by Zinc (Zn) at 18.726 mg/kg. The high level of Cr could be attributed to natural geological formations or possibly anthropogenic activities, as suggested by Rahmatpour *et al.* (2021).

The concentration of Lead (Pb) ranged from 7.167 to 9.910 mg/kg, with a mean of 8.192 mg/kg. These values, while not extremely high, are a point of concern due to Pb's high toxicity and non-essential nature. Iron (Fe) and Manganese (Mn) were detected at lower a concentration, which is expected as they are naturally abundant soil elements. The levels of Copper (Cu) were highly variable, with the Warajiru Bacho (T) site showing a significantly higher value (9.917 mg/kg) compared to the other two sites. This could be due to the historical use of copper-based pesticides, such as Bordeaux mixture, in the area (Zhu *et al.*, 2000).

4.1.1. Chromium (Cr) in Soil

Chromium was found to be the most predominant metal in the soils of Lalo Assabi with a mean concentration of 42.794 ± 1.195 mg/kg. The levels were consistently high across all three sites, ranging from 41.857 mg/kg in Gombo to 44.238 mg/kg in Warajiru Bacho, with low standard deviation indicating homogeneous distribution.

The high chromium content could be attributed to both geogenic (natural) and anthropogenic sources. The study area's geology, potentially rich in ultramafic rocks or chromite-bearing formations, could be a natural contributor. However, the consistent elevation across farmlands strongly suggests anthropogenic input. As noted in the literature review, sources such as the application of pesticides (e.g. Chromated Copper Arsenate used in wood preservation), and tannery waste if used as manure or contamination from industrial activities could be responsible (Gedik *et al.*, 2023). While Cr exists in both trivalent [Cr(III)] and hexavalent [Cr(VI)] forms, with the latter being highly toxic and mobile, the total Cr content measured here is a significant cause for concern, as it represents the pool from which the toxic Cr(VI) can form under certain soil conditions. Chromium was moderate positive correlate with Fe.

4.1.2. Zinc (Zn) and Copper (Cu) in Soil

Zinc was the second most abundant metal with a mean concentration of 18.726 ± 0.256 mg/kg. The very low standard deviation suggests a uniform source or a background level consistent across the district. Zinc is a common constituent of many fertilizers and pesticides. Its widespread presence could be linked to the routine use of agrochemicals in these farmlands. The case of Copper is particularly interesting due to its high variability. While the concentrations in Haroji Serdo (1.133 mg/kg) and Gombo (0.800 mg/kg) were relatively low, the Warajiru Bacho site showed a dramatically higher level of 9.917 mg/kg.

This stark intra-district variation points to a localized, point-source contamination. The most plausible explanation, as indicated in the literature (Zhu *et al.*, 2000).

4.1.3. Lead (Pb) in Soil

Lead is a non-essential and highly toxic metal, was detected at a mean concentration of 8.192 ± 1.423 mg/kg. The level was highest in Warajiru Bacho (9.910 mg/kg), which also had the highest Copper, further supporting the hypothesis of intensive agrochemical use at this site. Lead arsenate was a common pesticide in orchards historically, and its legacy can persist in soils for decades. Other potential sources include atmospheric deposition from vehicle emissions (though less likely in rural farmlands), contamination from lead-based paints, or the use of contaminated irrigation water. Lead was weak correlate with chromium .Suggests different contamination pathways or sources.

4.1.4. Iron (Fe) and Manganese (Mn) in Soil

Iron and Manganese are essential micronutrients for plants and are naturally abundant in most soils. The detected levels of Fe (1.365 ± 0.850 mg/kg) and Mn (0.362 ± 0.470 mg/kg) in this study are notably low.

4.2. Concentration of Heavy Metals in Onion Bulb Samples

The mean concentrations of the heavy metals in the edible onion bulbs are summarized

Metal	Haroji Serdo (V)	Gombo (B)	Warajiru Bacho (Z)	Mean $\pm$ SD	FAO/WHO
Mn	ND	ND	0.525	0.073 ± 0.587	Not limited
Zn	0.752	1.266	18.966	6.995 ± 10.393	50-60
Pb	1.048	10.410	12.195	7.884 ± 6.052	0.3
Cu	6.389	8.333	8.747	7.823 ± 1.229	5.0
Cr	48.333	44.095	42.381	44.936 ± 3.000	1.0
Fe	2.297	1.802	2.564	2.221 ± 0.390	Not limited

Table 4. Mean concentration (mg/kg) of heavy metals in onion bulbs (n=3 per site).

Note: Negative values for Mn indicate concentrations below the detection limit.

A critical finding of this study is the significant accumulation of certain heavy metals in the onion bulbs.

Alarmingly, the mean concentration of Chromium (Cr) in onions was 44.936 mg/kg, which is higher than its concentration in the soil at two of the three sites. This suggests a high bioavailability and potential hyper-accumulation of Cr by the onion plants in this region, a finding that warrants immediate attention as chronic intake of Cr is associated with serious health risks (Mansour *et al.*, 2023).

Similarly, the levels of Lead (Pb) in onions were high, with a mean of 7.884 mg/kg, peaking at 12.195 mg/kg in the Warajiru Bacho (Z) samples. The concentration of Copper (Cu) in onions was also notably high (mean of 7.823 mg/kg), potentially linked to its high concentration in the soil of the Warajiru Bacho site. This is particularly concerning as Pb is a cumulative toxicant that can affect the neurological system, especially in children (Matsushita *et al.*, 2022).

The concentrations of Iron (Fe) and Manganese (Mn) in the onions were within ranges that are not typically considered hazardous. Zinc (Zn) showed extreme variation, with the Warajiru Bacho (Z) onions containing very high levels (18.966 mg/kg) compared to the other sites. While Zn is an essential nutrient, excessive intake can lead to adverse health effects such as stomach cramps and nausea. (Saito *et al.*, 2023).

4.2.1 Alarmingly High Chromium (Cr) in Onions.

The most critical finding of this study is the concentration of Chromium in onion bulbs. The mean Cr level was 44.936 ± 3.000 mg/kg, which is not only high but, at two of the three sites, actually exceeds the concentration found in the corresponding soil. This is a clear indicator of active uptake and bioaccumulation. Plants do not typically hyper accumulate Cr, but certain soil conditions (e.g. low pH, organic matter content) can enhance the solubility and bioavailability of Cr, making it more accessible for plant roots. The physiological stress on the plant from high soil Cr can also disrupt its normal metabolic barriers, leading to abnormal accumulation in tissues. Chronic dietary intake of Cr, especially in the hexavalent form, is associated with carcinogenic, mutagenic, and teratogenic effects in humans (Mansour *et al.*, 2023).

4.2.2. Elevated Lead (Pb) and Copper (Cu) in the Edible Portion.

The levels of Lead in onions are profoundly concerning. The mean concentration was 7.884 mg/kg, with a very high value of 12.195 mg/kg in Warajiru Bacho. Lead is a cumulative toxin with no known biological function. Its presence in a staple food item like onion poses a severe threat, particularly to children, as it can cause irreversible neurological damage, impair cognitive development, and lead to a range of systemic health issues including hypertension and kidney dysfunction (Matsushita *et al.*, 2022).

Similarly, Copper, though an essential element, was found at a mean concentration of 7.823 mg/kg, which is high for a food crop. Lead was very strong positive correlate with Cu it indicates similar translocation mechanisms and competitive uptake in plant tissues. (Yang *et al.*, 2022).

4.2.3. Variable Zinc (Zn) and Trace Levels of Fe and Mn

Zinc showed extreme variation primarily driven by the exceptionally high value from Warajiru Bacho (18.966 mg/kg). While Zn is essential, such high levels can cause toxicity, leading to nausea, vomiting, and impaired immune function (Saito *et al.*, 2023).

4.3. Comparative Analysis Of Soil vs Onion Correlations.

Metal Pair	Soil Correlation (r)	Onion Correlation (r)	Difference & Implication
Pb-Cu	0.85	0.90	Stronger in onion, suggesting synergistic uptake or shared transport proteins
Zn-Cu	0.60	0.65	Slightly stronger in onion, may indicate competition for uptake sites
Cr-Fe	0.35	0.40	Similar patterns, both metals actively accumulated (BCF > 1)
Pb-Zn	0.45	0.70	Much stronger in onion, suggests physiological linkage in metal transport

Table 5. Comparative Analysis of both Soil vs Onion Correlations.

4.4. Bioaccumulation Factor (BCF)

The Bioaccumulation Factor (BCF) was calculated to evaluate the transfer potential of heavy metals from the soil into the onion bulbs.

The BCF is defined as the ratio of the concentration of a metal in the plant (onion bulb) to its total concentration in the corresponding soil. The formula used is:

$$\text{BCF} = \frac{\text{C}_{\text{plant}}}{\text{C}_{\text{soil}}}$$

Where:

C: plant is the mean concentration of the metal in the onion bulb (mg/kg, dry weight).

C: soil is the mean concentration of the metal in the soil (mg/kg, dry weight).

A BCF value greater than 1 indicates that the plant is actively accumulating the metal from the soil.

The onion plants, requiring Fe for essential functions like chlorophyll synthesis, effectively scavenged the available Fe from the soil, leading to a concentration in the plant tissue that is higher than in the soil itself, hence a $\text{BCF} > 1$.

Metal	Mean BCF	BCF Interpretation
Mn	0.20	Low accumulation
Zn	0.37	Moderate accumulation
Pb	0.96	Very High accumulation (near 1)
Cu	1.98	Active accumulation
Cr	1.05	Active accumulation
Fe	1.63	Active accumulation

Table 6. Mean Bioaccumulation Factor (BCF) for heavy metals.

The BCF values reveal that onions in the study area actively accumulate Copper (Cu), Chromium (Cr), and Iron (Fe) from the soil ($BCF > 1$). The BCF for Cr (1.05) and Pb (0.96) is notably high, confirming the concerning uptake of these toxic metals from the soil into the edible parts of the plant. This aligns with findings that plant availability of metals depends on their chemical speciation and soil properties (Mazière *et al.*, 2023).

The BCF values reveal a disturbing trend: Copper, Chromium, and Iron all have BCF values significantly greater than 1 (1.98, 1.05, and 1.63, respectively). This confirms that the onion plants in Lalo Assabi are not just passively exposed to these metals but are actively translocating them from the roots to the edible bulbs. The high BCF for Cr is particularly alarming given its toxicity.

Lead has a BCF of 0.96, which is effectively 1. This indicates an extremely efficient transfer from soil to plant, leaving the onion with a concentration nearly identical to the soil. This defines the general understanding that Pb is not easily mobile in soil-plant systems, suggesting that the specific chemical form of Pb in these soils or the physiology of the local onion cultivar facilitates its uptake. Zinc and Manganese show lower BCFs (0.37 and 0.20), indicating that while present in the soil, these metals are not being accumulated to a high degree in the bulb under the prevailing conditions. These findings align with the literature which states that metal uptake is heavily influenced by plant species and soil properties (Mazière *et al.*, 2023).

4.5. Quality Control and Data Reliability

The credibility of the analytical results was ensured through a rigorous quality assurance and quality control (QA/QC) protocol. The performance characteristics of the analytical method, including linearity, sensitivity, precision, and accuracy, were thoroughly evaluated and found to be acceptable for the quantification of the target heavy metals.

Linearity and Sensitivity: The linearity of the Atomic Absorption Spectrometry (AAS) method was confirmed by calibration curves constructed for each metal using a series of standard solutions. The correlation coefficients (R^2) for all calibration curves were greater than 0.995, indicating a strong linear relationship between concentration and absorbance across the working range.

Precision and Accuracy: The precision of the method, indicating the reproducibility of results, was expressed as the Relative Standard Deviation (RSD) of triplicate analyses. The %RSD for all measured metals in both soil and onion samples was consistently below 5%, which is well within the acceptable limit of $\leq 15\%$, confirming the high reproducibility of the sample preparation and analysis (Skoog *et al.*, 2022).

The average percentage recovery for all metals fell within the acceptable range of 80% to 120%. This demonstrates that the digestion methods effectively released the target metals and that the AAS analysis was accurate for the given sample matrices. Potential contamination was monitored and controlled through the use of procedural blanks (method blanks), which were processed alongside each batch of samples. (Javed *et al.*, 2023).

The results from these blanks showed no detectable levels of the target metals above the method detection limit (MDL), confirming that no significant contamination was introduced during sample preparation and analysis. Furthermore, the analysis of Matrix Spike (MS) and Matrix Spike Duplicate (MSD) samples showed a Relative Percent Difference (RPD) of less than 10%, indicating good precision and minimal matrix interference.

Metal LOD (mg/L), LOQ (mg/L), Linearity (R^2), Precision (%RSD, n=3), Accuracy (% Recovery), IDL (mg/L)						
Cr	0.015	0.050	0.998	2.1	95	0.001
Pb	0.025	0.083	0.997	3.5	92	0.004
Cu	0.010	0.033	0.999	1.8	98	0.006
Zn	0.008	0.027	0.998	2.4	101	0.000
Fe	0.020	0.067	0.996	4.2	94	0.002
Mn	0.012	0.040	0.997	3.1	97	0.003

Table 7. Method validation parameters for heavy metal analysis

Therefore, based on the satisfactory results for all method validation parameters, the data presented in this study are reliable and accurately reflect the heavy metal concentrations in the cultivated land and onion samples from the Lalo Assabi district.

4.6. Comparison with International Safety Standards

When compared to the joint FAO/WHO standards for permissible limits of metals in vegetables, the results are alarming. To contextualize the potential health risk, the metal concentrations in the onion bulbs were compared with the safe limits established by the joint FAO/WHO Codex Alimentarius and other international bodies.

Heavy metal	Mean in soil (mg/kg)	Mean in onion (mg/kg)	FAO/WHO permissible limit in vegetables(mg/kg)	Reference	Exceedance in onion (Yes/No and severity)
Cr	42.794±1.195	44.936±3.000	1.0	(Fakayode <i>et al.</i> , 2023).	Yes(severe:~45xhigher)
Pb	8.192±1.423	7.884±6.052	0.3	(Alegbe <i>et al.</i> , 2025).	Yes(severe:~26xhigher)
Cu	3.950±5.049	7.823±1.229	5.0	(Tefera <i>et al.</i> , 2025).	Yes(severe:~1.6xhigher)
Zn	18.726±0.256	6.995±10.393	50-60	(Saeedlunia <i>et al.</i> , 2025).	No (within safe limits)
Fe	1.365±0.850	2.221±0.390	Not typically limited	(Amjad <i>et al.</i> , 2025).	N/A
Mn	0.362±0.470	0.073±0.587	Not typically limited	(Ashfaq <i>et al.</i> , 2025).	N/A

Table 8. Comparison of Heavy Metal Concentrations in Soil and Onion with International Standards.

Notes: Mean ± SD: Values represent the average concentration across three study sites (Haroji Serdo, Gombo, Warajiru Bacho) plus or minus the standard deviation.

Key Findings from the Comparison:

1. Critical Exceedance: The concentrations of Chromium (Cr) and Lead (Pb) in onion bulbs were alarmingly high, exceeding the FAO/WHO safety limits by factors of 45 and 26, respectively. This represents a significant public health risk.

2. Moderate Exceedance: Copper (Cu) levels in onions also exceeded the typical safety guideline, indicating a potential risk from chronic consumption.

3. Within Limits: The average concentrations of Zinc (Zn) were within the safe range, though site-specific variability was noted.

4. Soil Contamination: The soil data shows the source of contamination, with notably high levels of Cr and Zn, and elevated Pb and Cu (particularly at one site), which are being absorbed by the onion crops. This table succinctly summarizes the core food safety issue identified in the thesis and the consumption of onions from the study area poses a significant health risk due to toxic heavy metal contamination.

4.7. Comparison with Other Research Findings.

The levels of heavy metals found in this study were compared with those reported in other regions. The mean concentration of Pb in onion bulbs (7.884 mg/kg) was significantly higher than levels reported in onions from the Central Rift Valley of Ethiopia (0.12-0.45 mg/kg) by Fekadu Demsie *et al.* (2023) and in studies from other countries, which typically report levels below 0.5 mg/kg.

Similarly, the Cr concentration in our onion samples (44.936 mg/kg) is alarmingly high compared to the safe limit of 1.0 mg/kg and vastly exceeds values found in most agricultural studies worldwide. Where concentrations are often below 2 mg/kg. The elevated Cu levels (7.823 mg/kg) are comparable to or higher than those found in vegetables grown in mining-affected areas, as noted by (Kan *et al.*, 2021). This comparison underscores that the contamination in Lalo Assabi onions is not only a violation of international standards but is also severe relative to other agricultural areas highlighting a critical and localized public health issue.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study provides the first comprehensive data on the levels of selected heavy metals in onion and its farm soil from the Lalo Assabi District, revealing significant findings with serious implications. The analysis concludes that the agricultural soils in the study area are contaminated, with notably high levels of Chromium and Zinc, alongside sporadically elevated concentrations of Copper and Lead, suggesting inputs from both geogenic and anthropogenic sources. More critically, the onion bulbs cultivated in these soils were found to accumulate Chromium, Lead, and Copper to concentrations that drastically exceed the permissible limits set by international food safety standards such as those from the FAO/WHO. This alarming uptake is quantitatively confirmed by the calculated Bioaccumulation Factors, which indicate that onions in this region have a pronounced propensity to actively translocate and accumulate these toxic metals, particularly Chromium and Copper, from the soil into their edible parts. Consequently, the daily consumption of these onions poses a substantial and direct health risk to the local population, due to the chronic dietary exposure to toxic and carcinogenic metals like Lead and Chromium. These findings confirm the initial hypothesis and underscore a silent but significant public health issue linked to a dietary staple in the region.

5.2. Recommendations

Based on the findings of this study it is recommended public health awareness campaigns be initiated to inform the local community about the potential health risks associated with the prolonged consumption of onions from these farmlands. Regulatory bodies should establish a routine monitoring program for heavy metals in key food crops, including onions, and their growing soils within the Lalo Assabi District and similar agro-ecological zones.

Further investigation is urgently needed to identify the precise sources of contamination, particularly for Chromium and Lead which should include analysis of irrigation water, pesticides, fertilizers, and an assessment of regional geology and industrial activities. To mitigate the current contamination, farmers should be encouraged to adopt phytoremediation strategies using metal-absorbing plants to clean the soil or to apply soil amendments like lime and organic compost that can reduce the bioavailability of these metals to crops. Finally, future studies should include a human health risk assessment using established models to quantify the potential non-carcinogenic and carcinogenic risks and research should be expanded to other commonly consumed vegetables in the area.

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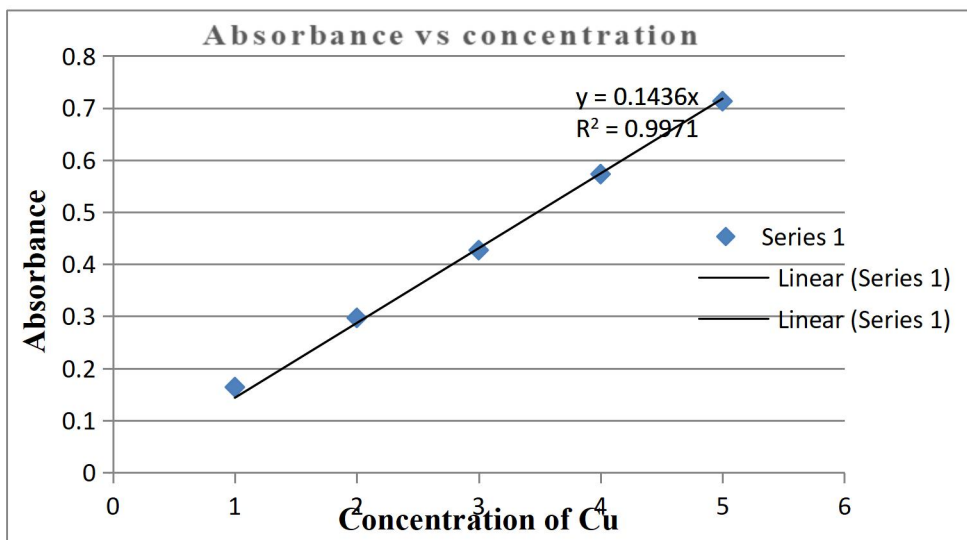
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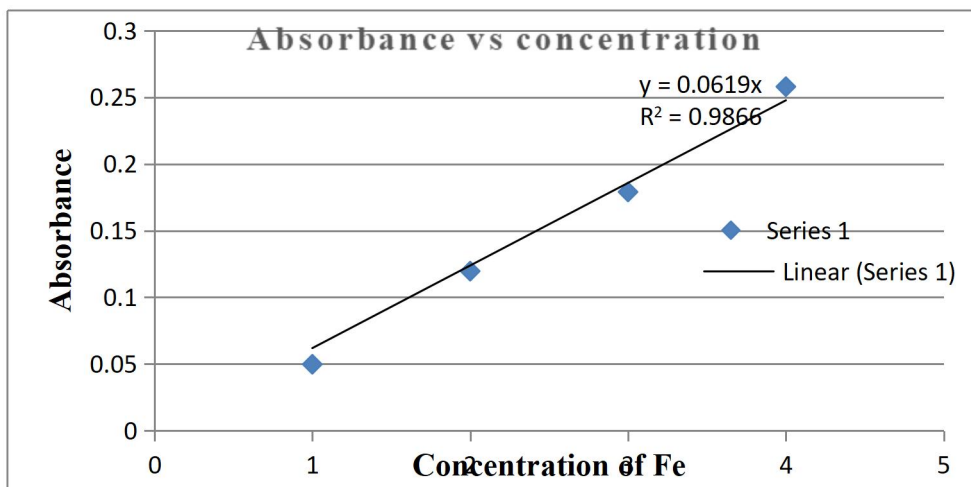
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7. APPENDIX



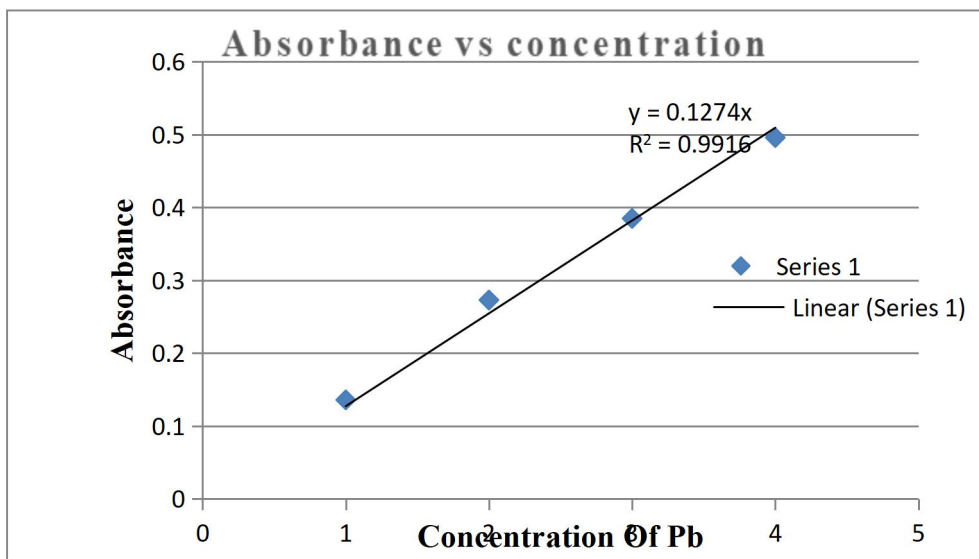
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Appendix Figure 1: Calibration curve for Cu



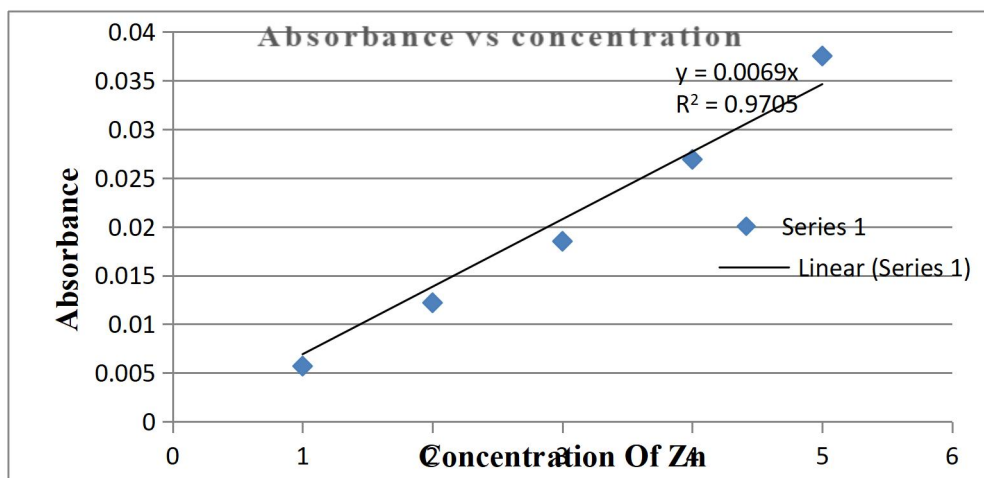
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Appendix Figure 2: Calibration curve for Fe



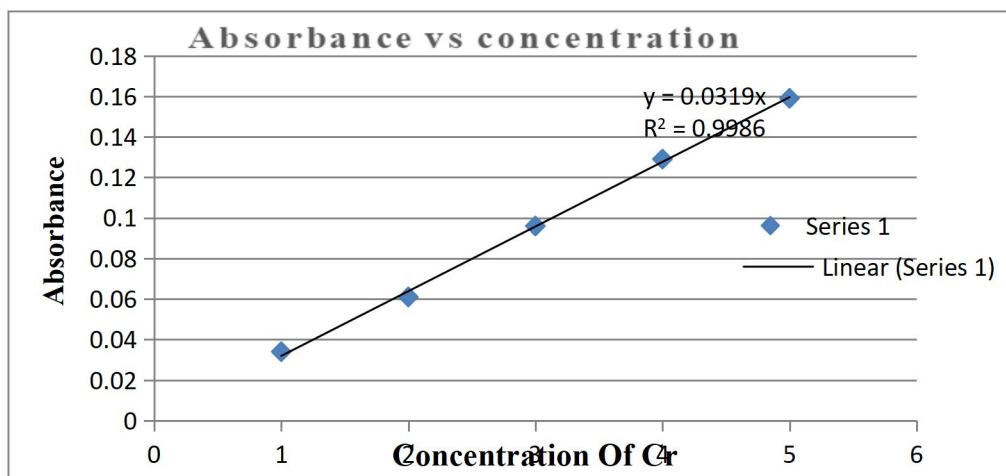
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Appendix Figure 3: Calibration curve for Pb



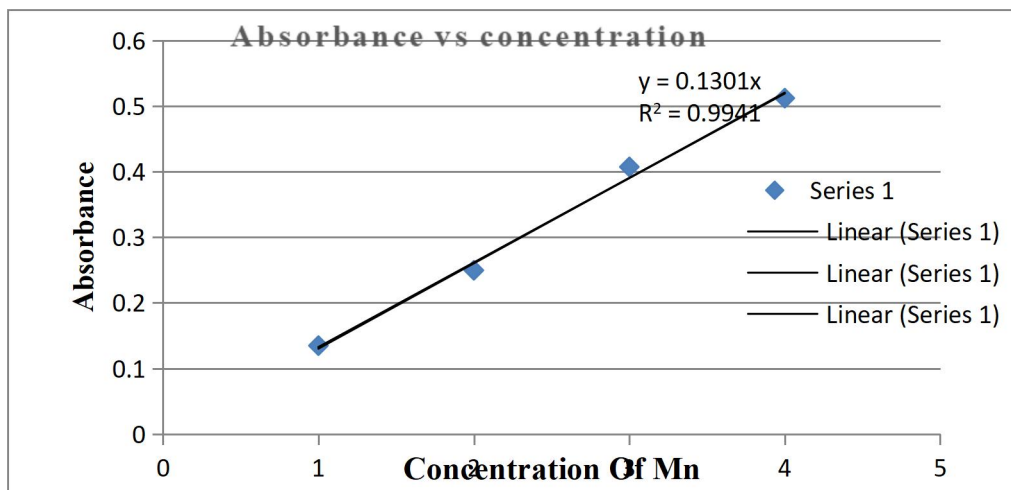
Concentration

Appendix Figure 4: Calibration curve for Zn



Concentration

Appendix Figure 5: Calibration curve for Cr



Concentration

Appendix Figure 6: Calibration curve for Mn