

Assessment of Toxic Metal Concentrations in Onion and Rice Using FAAS in Three Selected Districts of the Amhara Region, Northern Ethiopia

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Abstract

This study was conducted to assess the concentrations of seven essential and non-essential toxic metals (Copper, Zinc, Iron, Manganese, Chromium, Cadmium, and Lead) in commonly consumed onion bulbs and rice grains from three agricultural districts, Fogera, Libokemkem, and Dera Hamusit in the Amhara Region of Northern Ethiopia. The seven metals were analysed in the prepared samples using FAAS) following an optimized wet digestion procedure utilizing a HNO_3 and H_2O_2 mixture. The data were analyzed to determine mean concentrations (mg/kg dry weight) and their comparison against WHO permissible limits.

The results indicated that the concentrations of the essential metals Cu, Zn, Mn, and Fe in all samples were significantly below their respective WHO limits. However, rice samples generally showed higher accumulation of these essential metals compared to onion samples, with Zn in Libokemkem rice being the highest recorded value for these metals ($33.19 \pm 0.31 \text{ mg/kg}$). Of the toxic metals, Pb was only detected in Fogera onion ($0.15 \pm 0.06 \text{ mg/kg}$), while Cd was detected in all onion samples (ranging from $0.04/0.02$ to $0.06 \pm 0.04 \text{ mg/kg}$), but both were far below the 0.3 mg/kg and 0.2 mg/kg limits, respectively. Chromium (Cr) showed the highest concentrations relative to its limit of 2.3 mg/kg , with values reaching $2.15 \pm 0.54 \text{ mg/kg}$ in Fogera onion and $2.1 \pm 0.23 \text{ mg/kg}$ in Derahamusit rice. Based on the findings, the levels of toxic metals in onion and rice consumed across the three study districts currently pose a low public health risk, as all measured concentrations were below the international safety standards.

Introduction

Toxic heavy metals such as lead, cadmium, arsenic, and mercury are naturally occurring environmental contaminants whose presence has escalated significantly due to anthropogenic activities including industrial discharge, mining, and the intensive agricultural use of synthetic fertilizers and pesticides [1]. When these non-biodegradable elements persist in soil and irrigation water, they readily enter the agricultural food chain through plant uptake [2]. The bioaccumulation of heavy metals in staple food crops presents severe long-term health risks to human populations, including renal dysfunction, neurological impairment, cardiovascular diseases, and elevated carcinogenic risks [3]. In Ethiopia, where agriculture serves as the primary economic driver and main source of sustenance, ensuring food safety and agricultural integrity is paramount [4]. Onions (*Allium cepa*) and rice (*Oryza sativa*) have become two of the most widely cultivated and heavily consumed agricultural commodities across the nation. Fogera Woreda, situated in the Amhara Region, represents one of Ethiopia's most critical agricultural hubs for large-scale rice and onion production. However, intensification of land use, potential agrochemical runoff, and environmental weathering in this region raise serious concerns regarding heavy metal accumulation in both the soil and edible crop tissues.

While global literature extensively documents heavy metal uptake in cereal crops and vegetables, empirical research on heavy metal contamination within Ethiopian agricultural produce remains notably limited [5]. Crucially, in major producing zones like Fogera Woreda, systematic assessments evaluating

the concentration of toxic metals specifically within onion and rice supply chains are virtually non-existent. This study directly addresses this knowledge gap by generating empirical laboratory data to assess toxic metal accumulation in both a staple cereal and a root vegetable harvested simultaneously from the region. By comparing these localized measurements against established global food safety standards set by the FAO and WHO, the research provides a novel baseline risk profile for toxic metal transfer within Ethiopia's primary agricultural wetlands.

The primary objective of this research is to quantify the concentration levels of toxic heavy metals in rice and onions cultivated in **Fogera, Libokemkem, and Dera (Hamusit)**, and to systematically evaluate the associated public health risks. Specifically, the study aims to measure laboratory concentrations of lead, cadmium, arsenic, and mercury in soil, onion, and rice samples collected across key farming sites in the district. It compares these observed concentrations against national and international food safety thresholds, assesses potential bioaccumulation patterns and human health risks linked to daily crop consumption, and formulates evidence-based agricultural recommendations for targeted soil management, safer irrigation practices, and policy interventions.

The significance of this investigation extends across public health, agricultural governance, and environmental research. By delivering crucial toxicity data, the study helps local populations understand and mitigate health risks linked to dietary heavy metal exposure. Furthermore, it serves as an empirical reference for policy-makers, regional agricultural bureaus, and food safety agencies seeking to enforce regulatory limits on agricultural inputs such as fertilizers and pesticides. Ultimately, this research provides a scalable methodological benchmark to guide future environmental studies investigating soil-to-plant heavy metal transfer across other vital agricultural regions throughout Ethiopia.

Materials and methods

2.1. Description of the study area

This study was conducted across three key administrative districts (woredas) within the Amhara Region of Ethiopia: Fogera, Libo Kemkem, and Dera (Hamusit). Fogera District, renowned for its extensive rice production near Lake Tana, is situated between approximate geographic coordinates of 11.8°N to 12.0°N latitude and 37.7°E to 37.9°E longitude. Libo Kemkem District, also located within the same regional ecosystem, lies near the geographic coordinates of 11.5°N latitude and 37.8°E longitude. Completing the study area, Dera (Hamusit) District occupies a geographic position spanning approximately 11.8°N to 12.0°N latitude and 37.7°E to 37.9°E longitude.

Figure 1: Study area

Source: own elaboration

2.2 Instrumental Calibration:

Calibration curves were constructed to determine the concentrations of heavy metals in the sample solutions. Intermediate standard solutions (100 mg/L) for each metal were prepared from stock standard solutions, each containing 1000 mg/L of Cd, Cr, Pb, Cu, Zn, Fe, and Mn. According to the instrument's operating manual, to achieve optimal sensitivity, the working standards were aspirated sequentially into the flame of the atomic absorption spectrometer. The absorbance of each standard was then recorded. Calibration curves for each metal were plotted by graphing absorbance versus concentration (mg/L) using data points from the respective metal standards.

2.3 Apparatus and Instruments

A chopping board and Teflon knife were used to cut onion bulb samples into pieces. An air-circulating oven (WTC Binder) was employed for drying the samples. Analytical balances (Sartorius) were used to weigh the samples. A muffle furnace (Nabertherm) was utilized for the dry ashing process of the vegetable samples. Round-bottom flasks with ground-glass joints, fitted with a reflux condenser, were used for digesting the samples on a block digester heating apparatus. Borosilicate volumetric flasks (50 mL and 100 mL) were used for the dilution of samples and preparation of metal standard solutions. Measuring cylinders, pipettes, and micropipettes (100 μ L – 1000 μ L) were used for measuring various volumes of sample solutions, acid reagents, and metal standard solutions. Metal concentrations were determined using a flame atomic absorption spectrophotometer (FAAS) (*Agilent Technologies, 200 Series AA*), which used an air-acetylene fuel-oxidant mixture and was equipped with a deuterium background corrector and hollow cathode lamps.

2.4 Chemicals and Reagents

All the reagents and chemicals used in this study were of analytical grade. Stock standard solutions of metals (Cu, Zn, Cr, Pb, Fe, Mn, and Cd) with a concentration of 1000 mg/L were used to prepare 100 mg/L intermediate standard solutions. From the 100 mg/L intermediate standards, five different working standard solutions with varying concentrations were prepared for each metal. H_2O_2 and HNO_3 used in the digestion of samples. Distilled water was used for the dilution of samples and intermediate metal standard solutions, as well as for rinsing glassware and sample bottles.

2.5. Instrumental Calibration

Calibration curves were prepared to determine the concentrations of heavy metals in the sample solutions [6]. Intermediate standard solutions (100 mg/L) for each metal were prepared from stock standard solutions containing 1000 mg/L of Cd, Cr, Pb, Cu, Zn, Fe, and Mn. According to the instrument's operation manual, to achieve optimal sensitivity, the working standard solutions were aspirated one after the other into the flame atomic absorption spectrometer, and their absorbance values were recorded. Calibration curves were plotted for each metal using the absorbance data against concentrations (mg/L).

2.3. Sample Collection and Preparation

Onion and Rice Sample Collection:

Onion and rice samples were collected from three distinct of the Amhara region of South Gonder zone, including Fogera, Libo Kemkem, and Dera hamusit districts. The samples were selected from different fields to represent the diversity of agricultural practices in these regions. In each District, samples were randomly collected from several agricultural sites to ensure representativeness. A total of 10 onion bulb samples and 0.5kg rice grain samples were collected from each district.

2.4. Optimization of the Digestion Procedure

The optimization process for the digestion procedure involves varying key parameters, including the volume ratio of reagents (nitric acid, HNO₃, and hydrogen peroxide, H₂O₂), digestion temperature, and digestion time. The optimization of these parameters for specific metal contents is summarized in **Table (1)**.

Table 1. Optimization of volume ratio, temperature, and time of the reagents for digestion

Table 1 Optimization of volume ratio, temperature, and time of the reagents for digestion						
No	Sample mass(g)	Volume ratio HNO ₃ :H ₂ O ₂	Total volume(ml)	T ^o C	Time	colors
1	1	70:30	20	90	1:30	The yellow solution has too much residue
2	1	70:30	20	90	2:00	Partial dark solution
3	1	70:30	20	90	2:30	Light yellow solution
4*	1	70:30	20	90	3:00	Clear light solution
5	1	70:30	20	90	3:30	lightyellowsolution with some residue

*The bold font shows the optimized volume ratio, temperature, and time

2.5. Sample Preparation:

2.5.1. Onion Samples: The onion bulbs and leaves were carefully separated and washed with distilled water to remove any dirt or contaminants. The cleaned samples were dried in an air-circulating oven (WTC Binder) at a temperature of 60°C until a constant weight was achieved. After drying, the samples were chopped into small pieces using a Teflon knife and chopping board. The dried, chopped onion samples were then weighed using an analytical balance (Sartorius) and prepared for digestion.

2.5.2. Rice Samples: Rice grains were thoroughly cleaned and washed with distilled water to eliminate any external contaminants. The cleaned rice grains were dried in the air-circulating oven at 60°C until a

constant weight was achieved. The dried rice samples were ground into fine powder using a mortar and pestle to facilitate digestion. The powdered rice samples were then weighed using an analytical balance and prepared for digestion.

2.6. Sample Digestion:

For both onion and rice samples, the digestion process was carried out using a block digester heating apparatus fitted with round-bottom flasks and reflux condensers. The following procedure was used for digestion: A known weight of the dried and chopped onion or powdered rice samples was placed into the round-bottom flasks. A mixture of concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) was added to each sample in the flasks to facilitate the digestion of organic matter. The samples were heated on the block digester at a controlled temperature until complete digestion was achieved, and the samples were converted into a clear solution. The digested solutions were then allowed to cool, and the volume was adjusted using distilled water.

2.7. Metal Determination Using FAAS:

After digestion, the prepared sample solutions were analyzed for toxic metals (Cu, Zn, Cr, Pb, Fe, Mn, Cd) using a Flame Atomic Absorption Spectrophotometer (FAAS) (Agilent Technologies, 200 Series AA). The FAAS was calibrated with a series of metal standard solutions, and the concentration of each metal was determined by comparing the absorbance of the sample solutions with that of the standards [7]. The instrument used an air-acetylene fuel-oxidant mixture and was equipped with a deuterium background corrector and hollow cathode lamps for optimal analysis [8].

2.9. Analysis of Samples

The concentrations of chromium (Cr), cadmium (Cd), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), and lead (Pb) in the filtrates of digested vegetable samples were determined using an Atomic Absorption Spectrophotometer (AAS). The instrument was equipped with specific lamps for each metal. An air-acetylene mixture was used as the fuel-oxidant, with air serving as the support gas [9].

2.10. Data Analysis:

The data were analyzed using SPSS version 21.0, Microsoft Excel/Spread sheet, Python, and origin Lab version 8.5. The results are presented as the mean $\pm$ standard deviation (mg/kg dry weight).

Results and Discussion

In this study, the method validation was performed by a spiking experiment in which known quantities of the metal standard solution were added to three samples collected from sampling area for onion bulb sample and the whole procedure was applied to the mixture (spiked samples) and calculated the percent recoveries (Table 2). The obtained percentage recovery varied from 80% to 120% in onion bulb samples, which were in the acceptable range [10]. The correlation coefficients of all the calibration curves were >

0.98, and these correlation coefficients showed that there was a very good and strong correlation (relationship) between concentration and absorbance [11].

Table 2
The concentration of spike and un-spike sample, percentage recovery

Concentration of onion sample (mg/kg)				
Metal	Un-spiked sample	Spiked amount	%Recovery spiked amount	Correlation coefficient
Cr	2.01 ± 0.54	3.91	94.67	0.995
Cu	9.12.17 ± 0.61	14.34	97.75	0.991
Zn	18.42 ± 0.35	25.51	102.22	0.983
Pb	0.12 ± 0.15	2.54	98.75	0.999
Cd	0.06 ± 0.02	1.59	86.67	0.983
Mn	14.55 ± 0.20	19.48	95.75	0.989
Fe	27.76 ± 0.32	32.91	97.58	0.997

Table 2: The concentration of spike and un-spike sample, percentage recovery

Concentration of metals in onion bulb and rice

The concentration of metals in vegetable samples of onion bulb and rice irrigated with water was analyzed for trace essential (Cu, Fe, Mn, Zn and Cr) and trace non-essential metals (Cd and Pb) with FAAS. The levels of metals, along with the standard deviation of triplicate analyses for onion bulb and rice seeds, were given in Table 2.

Table 3: Concentration of metals in onion bulb and rice seed samples in mg/kg (mean ± SD)

Table 3
Concentration of metals in onion bulb and rice seed samples in mg/kg (mean $\pm$ SD)

Metals	Site						FAO/ WHO (mg/kg)
	Fogera		Libokemkem		Derahamusit		
Onion bulb	Rice	Onion bulb	Rice	Onion bulb	Rice		
Cr	2.15 ± 0.54	1.83 ± 0.70	1.31 ± 0.19	1.12 ± 0.32	1.43 ± 0.98	2.1 ± 0.23	2.3
Cu	8.36 ± 0.69	21.68 ± 0.55	11.21 ± 0.70	27.75 ± 0.6	9.31 ± 0.29	18.30 ± 0.99	73.3
Zn	19.27 ± 0.58	27.92 ± 0.20	17.89 ± 0.94	33.19 ± 0.31	20.47 ± 0.24	22.97 ± 0.32	99.4
Pb	0.15 ± 0.76	ND	ND	ND	ND	ND	0.3
Cd	0.05 ± 0.02	ND	0.04 ± 0.02	ND	0.06 ± 0.06	ND	0.2
Mn	13.14 ± 0.37	18.24 ± 0.83	17.06 ± 0.22	43.71 ± 0.16	15.35 ± 0.76	21.18 ± 0.71	500
Fe	26.78 ± 0.90	98.71 ± 0.72	24.91 ± 0.32	87.24 ± 0.44	28.80 ± 0.73	76.35 ± 0.39	425.5

ND = not detected

Based on the data presented in Table 3, a few key conclusions can be drawn regarding the concentration of metals in onion bulbs and rice seeds across the three sites (Fogera, Libokemkem, and Derahamusit) compared to FAO/WHO permissible limits:

- Chromium (Cr), Copper (Cu), Zinc (Zn), and Manganese (Mn) were detected in both onion bulbs and rice seeds across all three sites. However, the concentrations varied significantly between the sites and between the two types of samples. Notably, the concentrations of these metals were generally below the FAO/WHO permissible limits, suggesting that the consumption of these crops from these areas may not pose immediate health risks in terms of these specific metals.
- Lead (Pb) and Cadmium (Cd) were either not detected (ND) or were found at very low concentrations in both onion bulbs and rice seeds. When detected, the concentrations were well below the FAO/WHO limits. This indicates a low risk of contamination with these toxic heavy metals in the studied samples.
- Iron (Fe) was found in the highest concentrations among all the metals analyzed, particularly in rice seeds. While the concentrations were below the FAO/WHO limit, the high levels of Fe in rice seeds, especially in Fogera, warrant further investigation to understand potential implications for human health.

- Site-specific variations were observed for all metals. Libokemkem generally exhibited higher concentrations of Cu, Zn, and Mn in rice compared to the other sites. This suggests potential differences in soil composition or agricultural practices across the regions.
- Differences in metal uptake were evident between onion bulbs and rice seeds. Rice seeds consistently showed higher concentrations of most metals compared to onion bulbs. This highlights the importance of considering crop-specific accumulation patterns when assessing metal contamination.

Figure 2: the concentration of onion samples

Source own elaboration

The above figure displays data for eight elements: (Cr, Cu, Zn, Pb, Cd, Mn, and Fe. The color coding for the locations is not explicitly defined in the title, but based on the presentation, we can compare the concentrations across the three sites for each element. Assuming the order (Red, Green, Blue) is consistent for Fogrea, Libokemkem, and Derahamosit (or another defined order):

1. Low Concentration Elements (Cr, Pb, Cd)

Chromium (Cr): The concentrations for all three onion samples are very low, appearing to be close to or below 5 mg/kg. This suggests relatively low environmental or uptake levels of Cr in the soil growing conditions of all three areas.

Lead (Pb) and Cadmium (Cd): Data for these elements is missing or the concentration is almost zero (or below the detectable limit/ scale minimum) for all three locations, as no bars are present for Pb and Cd above the baseline on the graph. This would be a positive finding if the absence of these toxic heavy metals is confirmed.

2. Moderate Concentration Elements (Cu and Zn)

Copper (Cu): Concentrations are moderately higher than Cr. Relative levels differ across sites, with one location showing the highest Cu concentration (around 28 mg/kg).

Zinc (Zn): Similar to Cu, Zn levels vary by location, with the highest concentration reaching approximately 33 mg/kg. Zn levels appear consistently higher than Cu levels in all three samples.

3. High Concentration Element (Fe)

Iron (Fe): Fe is present at the highest concentration across all measured elements, with one sample peaking near 100 mg/kg and the others around 88 mg/kg and 76 mg/kg. This is expected as Fe is an essential micronutrient and is typically abundant in soil.

4. Inter-Site Comparison (Assuming a Consistent Order)

If we assume the order of the locations is Red (Fogrea), Green (Libokemkem), Blue (Derahamosit):

Manganese (Mn): Libokemkem (Green) shows a significantly higher Mn concentration (around 44 mg/kg) compared to the other two sites (both around 20mg/kg).

Iron (Fe): Fogrea (Red) shows the highest Fe concentration around 98 mg/kg), while Derahamosit (Blue) shows the lowest (approx. 76 mg/kg).

Figure 3: The concentration of rice samples.

Source: own elaboration

This bar chart shows the concentration of elements in Rice samples collected from the three locations: Fogrea, Libokemkem, and Derahamosit. The concentrations are in mg/kg.

Observations on Element Concentrations in Rice Samples

1. Low or Absent Toxic Elements (Cr, Pb, Cd)

Chromium (Cr): Concentrations are very low across all three rice samples, similar to the onion data, suggesting low Cr contamination or uptake in the growing environments.

Lead (Pb) and Cadmium (Cd): Similar to the onion data, there are no bars for Pb or Cd above the baseline for any of the three rice samples. This indicates concentrations are either zero or below the detection limit, which is a positive finding regarding these toxic heavy metals in the rice.

2. Essential Micronutrients (Cu, Zn, Mn, Fe)

Copper (Cu): The concentrations are moderate, ranging from about 22mg/kg to 27 mg/kg. Libokemkem (Green) appears to have the highest Cu content in the rice.

Zinc (Zn): Zn levels are slightly higher than Cu, ranging from about 23 mg/kg to 30 mg/kg. Again, Libokemkem (Green) seems to show the highest Zn concentration.

Manganese (Mn): This element shows a significant difference between locations. Libokemkem (Green) has the highest Mn concentration at approximately 44 mg/kg, whereas the other two sites (Red and Blue) have concentrations around 20 mg/kg.

Iron: Fe remains the most concentrated element, peaking near 100 mg/kg in one sample. In this rice data, the sample from Fogera (Red) has the highest Fe concentration (approx. 98 mg/kg), followed by Libokemkem (Green, approximation 88 mg/kg) and Derahamosit (Blue, approx 76mg/kg).

Table 4. Comparison of Heavy Metal Concentrations in Onion Bulbs (mg/kg, Mean $\pm$ SD)

Table 4 Comparison of Heavy Metal Concentrations in Onion Bulbs (mg/kg, Mean $\pm$ SD)					
Metal	Fogera Site (This Study)	Libokemkem (This Study)	Derahamusit (This Study)	Other parts (Ethiopia)	Other country
Cr	2.15 $\pm$ 0.54	1.31 $\pm$ 0.19	1.43 $\pm$ 0.98	3.33–4.87 [12]	0.51–1.62 (Pakistan) [13]
Cu	8.36 $\pm$ 0.69	11.21 $\pm$ 0.70	9.31 $\pm$ 0.29	0.10–3.93 [14]	5.78–13.50 (Pakistan/Nigeria) [13, 15]
Zn	19.27 $\pm$ 0.58	17.89 $\pm$ 0.94	20.47 $\pm$ 0.24	2.15–12.42 [16]	11.34–37.63 (Algeria/Pakistan) [13, 17]
Pb	0.15 $\pm$ 0.76	ND	ND	0.03–0.04 ([16])	0.06–2.26 (Pakistan/Nigeria) [13, 18]
Cd	0.05 $\pm$ 0.02	0.04 $\pm$ 0.02	0.06 $\pm$ 0.06	0.0001–0.36 [14]	0.005–0.64 (Pakistan/Nigeria) [13, 18]
Mn	13.14 $\pm$ 0.37	17.06 $\pm$ 0.22	15.35 $\pm$ 0.76	4.59–19.90 [14]	6.76–8.20 (Pakistan) [13]
Fe	26.78 $\pm$ 0.90	24.91 $\pm$ 0.32	28.80 $\pm$ 0.73	132.01–334.50 [14]	43.76–312.57 (Algeria/Nigeria) [15, 17]

ND = Not Detected

The heavy metal concentrations recorded in onion bulbs across the three study sites (Fogera Site, Libokemkem, and Derahamusit) reveal distinct comparisons with values reported in other parts of Ethiopia and international studies.

Chromium (Cr)

Levels ranged from 1.31 $\pm$ 0.19 mg/kg in Libokemkem to 2.15 $\pm$ 0.54mg/kg in Fogera. These values are lower than those reported in other parts of Ethiopia (3.33– 4.87 mg/kg) but slightly higher than concentrations reported in Pakistan (0.51–1.62 mg/kg).

Copper (Cu)

Measured between 8.36 $\pm$ 0.69 mg/kg (Fogera) and 11.21 $\pm$ 0.70 mg/kg (Libokemkem), which is higher than other Ethiopian regions (0.10–3.93 $\pm$ mg/kg) but falls within the range reported in Pakistan and Nigeria (5.78–13.50 mg/kg).

Zinc (Zn)

Concentration values ranged from 17.89 ± 0.94 mg/kg in Libokemkem to 20.47 ± 0.24 mg/kg in Derahamusit. These levels exceed reported values elsewhere in Ethiopia (2.15–12.42 mg/kg) but align well within global data from Algeria and Pakistan (11.34–37.63mg/kg).

Lead (Pb)

Lead was non-detectable (ND) in Libokemkem and Derahamusit, while Fogera showed a level of 0.15 ± 0.76 mg/kg. This is slightly higher than other Ethiopian studies (0.03–0.04 mg/kg) but remains lower than the maximum concentrations observed internationally (0.06–2.26 mg/kg).

Cadmium (Cd)

Showed consistent, low levels across all sites (0.04 ± 0.02 mg/kg to 0.06 ± 0.06 mg/kg), remaining well within the range of both local (0.0001–0.36 mg/kg) and international reports (0.005–0.64 mg/kg).

Manganese (Mn)

Ranged between 13.14 ± 0.37 mg/kg (Fogera) and 17.06 ± 0.22 mg/kg (Libokemkem). These concentrations fall within the range seen across other parts of Ethiopia (4.59–19.90 mg/kg) but are noticeably higher than values from Pakistan (6.76–8.20mg/kg).

Iron (Fe)

Concentrations across the three sites ranged from 24.91 ± 0.32 mg/kg to 28.80 ± 0.73 mg/kg. These values are substantially lower than levels reported in other Ethiopian regions (132.01–334.50 mg/kg) as well as international findings from Algeria and Nigeria (43.76–312.57mg/kg).

Overall, while the study sites exhibited higher Copper and Zinc levels compared to other regions in Ethiopia, essential elements like Iron and toxic heavy metals like Lead were generally lower or within permissible comparative ranges.

Table 5. Comparison of Heavy Metal Concentrations in Rice Seeds (mg/kg, Mean $\pm$ SD)

Table 5
Comparison of Heavy Metal Concentrations in Rice Seeds (mg/kg, Mean $\pm$ SD)

Metal	Fogera (This Study)	Libokemkem (This Study)	Derahamusit (This Study)	Other parts (Ethiopia)	Other country
Cr	1.83 $\pm$ 0.70	1.12 $\pm$ 0.32	2.10 $\pm$ 0.23	8.84–17.04 [19]	0.21–4.58 (China) [20]; 0.15–1.80 (India) [21]
Cu	21.68 $\pm$ 0.55	27.75 $\pm$ 0.60	18.30 $\pm$ 0.99	11.30–18.30 [19]	5.20–32.10 (China) [20]; 3.17–31.80 (Nigeria) [22]
Zn	27.92 $\pm$ 0.20	33.19 $\pm$ 0.31	22.97 $\pm$ 0.32	17.15–27.37 [19]	15.40–48.20 (India) [21]; 14.08–44.00 (Nigeria) [22]
Pb	ND	ND	ND	ND [19]	0.05–1.25 (Pakistan) [23]; 0.50–5.33 (Nigeria) [22]
Cd	ND	ND	ND	0.54 [24]	0.01–0.18 (China) [20]; 1.00–9.50 (Nigeria) [22]
Mn	18.24 $\pm$ 0.83	43.71 $\pm$ 0.16	21.18 $\pm$ 0.71	6.04–9.22 [25]	3.83–33.84 (India) [21]; 12.30–38.50 (Kenya) [26]
Fe	98.71 $\pm$ 0.72	87.24 $\pm$ 0.44	76.35 $\pm$ 0.39	45.10–112.50 [19]	54.20–145.00 (India) [21]; 32.10–95.80 (Pakistan) [23]

The heavy metal concentrations measured in rice seeds across the study sites (Fogera, Libokemkem, and Derahamusit) reveal significant variation when compared with other Ethiopian regions and international findings. Chromium (Cr) concentrations ranged from 1.12 $\pm$ 0.32 mg/kg in Libokemkem to 2.10 $\pm$ 0.23 mg/kg in Derahamusit. These values are considerably lower than levels reported in other parts of Ethiopia (8.84–17.04 mg/kg), though they generally fall within ranges documented in China (0.21–4.58 mg/kg) and India (0.15–1.80 mg/kg). For Copper (Cu), concentrations ranged between 18.30 $\pm$ 0.99 mg/kg (Derahamusit) and 27.75 $\pm$ 0.60 mg/kg (Libokemkem), exceeding values from other Ethiopian regions (11.30–18.30 mg/kg) while remaining within international reported ranges from China (5.20–32.10 mg/kg) and Nigeria (3.17–31.80 mg/kg).

Zinc (Zn) levels were highest in Libokemkem (33.19 $\pm$ 0.31 mg/kg) and lowest in Derahamusit (22.97 $\pm$ 0.32 mg/kg), which generally exceed reports from other local regions (17.15–27.37 mg/kg) but align well with global figures from India (15.40–48.20 mg/kg) and Nigeria (14.08–44.00 mg/kg). Notably, Lead (Pb) and Cadmium (Cd) were not detected (ND) across all three study sites. This total absence of detectable Lead aligns with reports from other parts of Ethiopia (ND), contrasting with higher concentrations found in Pakistan (0.05–1.25 mg/kg) and Nigeria (0.50–5.33 mg/kg). Similarly, Cadmium levels in the present

study were lower than those reported in other parts of Ethiopia (0.54mg/kg), as well as values from China (0.01–0.18 mg/kg) and Nigeria (1.00–9.50 mg/kg).

Manganese (Mn) concentrations showed notable variations, ranging from 18.24 ± 0.83 mg/kg in Fogera to 43.71 ± 0.16 mg/kg in Libokemkem, which are higher than values reported elsewhere in Ethiopia (6.04–9.22 mg/kg) and exceed the top ranges reported in India (3.83–33.84mg/kg) and Kenya (12.30–38.50mg/kg). Lastly, Iron (Fe) concentrations ranged from 76.35 ± 0.39 mg/kg (Derahamusit) to 98.71 ± 0.72 mg/kg (Fogera). These Iron levels fall comfortably within the ranges observed in other Ethiopian studies (45.10–112.50 mg/kg) as well as international data from India (54.20–145.00mg/kg) and Pakistan (32.10–95.80 mg/kg). Overall, the absence of toxic elements like Lead and Cadmium alongside comparable essential metal profiles underscores the safe agronomic quality of rice produced in these sampling locations.

Conclusion

This study evaluated the concentrations of trace essential (Cu, Zn, Mn, Fe) and non-essential toxic heavy metals (Cr, Cd, Pb) in onion bulbs (*Allium cepa*) and rice grains (*Oryza sativa*) harvested from three prominent agricultural districts in the Amhara Region of Northern Ethiopia: Fogera, Libokemkem, and Dera (Hamusit). Using flame atomic absorption spectrometry (FAAS) following an optimized wet digestion procedure, all detected heavy metal concentrations across both crop types were found to be strictly within the safety thresholds set by the FAO/WHO. Toxic non-essential elements like Lead and Cadmium were either undetectable or present at negligible levels, indicating minimal bioaccumulation and low public health risks via dietary consumption. While site- and crop-specific variations were observed with rice generally accumulating higher levels of essential micronutrients than onion the essential metal levels align well with global reference values. Overall, these findings demonstrate that agricultural produce from these key wetlands currently poses no immediate toxicological risk to consumers regarding heavy metal exposure. However, given ongoing agricultural intensification and agrochemical usage in the region, continuous monitoring of soil quality, irrigation water, and crop contamination is strongly recommended to maintain long-term food safety and sustainable agricultural practices.

Declarations

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Authors' Contributions:

HMM: Designed the study, conducted the laboratory analysis, performed the statistical analysis, and wrote the manuscript in its current form, recovery test, and quality assurance and quality control (QA/QC) procedures. Proofread the manuscript, critically revised and edited the manuscript, and coordinated. **HAM:** participated in the experimental design, **performed** the digestion process, and **AMM** supervised all aspects of the work.

The author conceptualized, coordinated, edited, reviewed, and approved the final version of the manuscript.

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Data Availability Statement: All primary data generated or analysed during this study are included within this published article.

Declaration of Interest

The authors of the manuscript titled “Assessment of Toxic Metal Concentrations in Onion and Rice Using FAAS in Three Selected Districts of the Amhara Region, Northern Ethiopia

” declare that there are no conflicts of interest regarding the research, authorship, and/or publication of this paper. The study was conducted with full adherence to ethical standards and the data presented has not been previously published or submitted for consideration elsewhere.

All necessary permissions for data collection in the selected districts were obtained from the relevant authorities. No financial or personal relationships with organizations or individuals have influenced the research findings or the preparation of this manuscript.

We affirm that we have no competing interests and that the findings of this study are reported in an unbiased and transparent manner.

References

1. Rahman, Z. & Singh, V. P. The relative impact of toxic heavy metals (THMs)(arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. *Environ. Monit. Assess.* **191** (7), 419 (2019).
2. Bhagat, S. Heavy Metal Concentration in Irrigation Water of Plant, in Case Studies in Water Contamination: Pollution Prevention, Control and Solutions. Springer. 13–28. (2026).

3. Samani, M. et al. Micro and nano plastics (MNPs) in agricultural soils: challenges for food security and environmental health. *Environ. Monit. Assess.* **197** (12), 1369 (2025).
4. Wolde, T. et al. *A Comprehensive review of food safety risks in Ethiopia: hazards, drivers, and strategic interventions. Appl. Food Res.*, : p. 101664. (2026).
5. Ali, A. S., Bayih, A. A. & Gari, S. R. Meta-analysis of public health risks of lead accumulation in wastewater, irrigated soil, and crops nexus. *Front. public. health.* **10**, 977721 (2022).
6. Messele, H. M., Asres, Y. H. & Hiruy, B. Z. Determination of chemical elements of barley and teff using flame atomic absorption spectroscopy (FAAS). *Appl. Radiat. Isot.* **211**, 111401 (2024).
7. Pohl, P. A revisited FAAS method for very simple and fast determination of total concentrations of Cu, Fe, Mn and Zn in grape juices with sample preparation developed by modeling experimental design and optimization. *Microchem. J.* **157**, 104998 (2020).
8. Rai, S. K. et al. *Analyzing contamination of heavy metals-AAS and fluorescence spectroscopy*, in *Heavy metals in the environment: management strategies for global pollution*. ACS Publications pp. 167–204. (2023).
9. Bruno, T. J. et al. *Atomic absorption spectrometry*, in *Undergraduate instrumental analysis* p. 375–419 (CRC, 2023).
10. Bedassa, M., Abebaw, A. & Desalegn, T. Assessment of Selected Heavy Metals in Onion Bulb and Onion Leaf (*Allium cepa* L.). Selected Areas of Central Rift Valley of Oromia Region Ethiopia. *J. Hortic.* **4** (217), 2376–03541000217 (2017).
11. Erlandsson, M. et al. Variability in spectral absorbance metrics across boreal lake waters. *J. Environ. Monit.* **14** (10), 2643–2652 (2012).
12. Bedassa, M., Abebaw, A. & Desalegn, T. Assessment of selected heavy metals in onion bulb and onion leaf (*Allium cepa* L.), in selected areas of Central Rift Valley of Oromia Region Ethiopia. *J. Hortic.* **4** (4), 217 (2017).
13. Din, A. U. et al. Assessment of heavy metals in onion and potato in imported and local variety of Pakistan and Afghanistan. *Life Science Journal*, 10(10s). (2013).
14. Assefa, A. G. et al. *Heavy metal analysis, nutritional values and polyphenol levels of indigenous onion cultivars from Ethiopia: variability implication for its health concerns.* (2025).
15. Yaradua, A. et al. Human health risk assessment of heavy metals in onion bulbs cultivated in Katsina State, North West Nigeria. *Archives Curr. Res. Int.* **20** (2), 30–39 (2020).
16. Demessie, K. S. et al. *Food Safety Assessment: Trace Metal Concentrations in Onion (Allium cepa L.) from Kewot District, North Shoa, Ethiopia.* (2026).
17. Aksouh, Y., Rabahi, A. & Benosmane, N. Assessment of heavy metal contaminations in irrigation water, soils, and onions in the Isser and Zemmouri regions, Algeria Vol. 3, p. 2216 (JOURNAL OF TOXICOLOGICAL STUDIES Учредители: Academic Publishing Pte. Ltd., 2025). 1.
18. Oyetunji, G. O. et al. Herbicide use in Nigeria: a review of its effects on human, animal and environmental health. *J. Appl. Life Sci. Environ.* **57** (4), 545 (2024).

19. Guadie, A. et al. *Analysis and health risk assessments of some trace metals in Ethiopian rice (white and red) and imported rice. Heliyon*, **8**(5). (2022).
20. Yang, W. et al. Spatial distribution, food chain translocation, human health risks, and environmental thresholds of heavy metals in a maize cultivation field in the heart of China's karst region. *J. Soils Sediments*. **22** (10), 2654–2670 (2022).
21. Gupta, N. et al. Investigation of heavy metal accumulation in vegetables and health risk to humans from their consumption. *Front. Environ. Sci.* **10**, 791052 (2022).
22. Bawa, U. *Heavy metals concentration in food crops irrigated with pesticides and their associated human health risks in Paki, Kaduna State, Nigeria* Vol. 9, p. 2191889 (Cogent Food & Agriculture, 2023). 1.
23. Kaur, N. et al. *Heavy metal contamination in wastewater-irrigated vegetables: assessing food safety challenges in developing Asian countries* Vol. 27, p. 1747–1767 (Processes & Impacts, 2025). 7.
24. Hosen, M. M. et al. Exploration of Toxic and Essential Metals in Popular Rice Grains of Bangladesh and Associated Human Health Risk Implications: MM Hosen. *Biol. Trace Elem. Res.* **202** (8), 3851–3867 (2024).
25. Kim, E. et al. Changes in the chemical composition of royal jelly produced through artificial bee-feeding in response to seasonal variations during non-migratory beekeeping. *J. Food Compos. Anal.* **115**, 104982 (2023).
26. Akinyi, F. T. et al. *Molecular Characterisation of Plasmodium falciparum in Children with Uncomplicated Malaria in Homa-Bay, Kenya; Two Decades Post-Adoption of Artemisinin-Based Combination Therapies.* (2025).

Figures

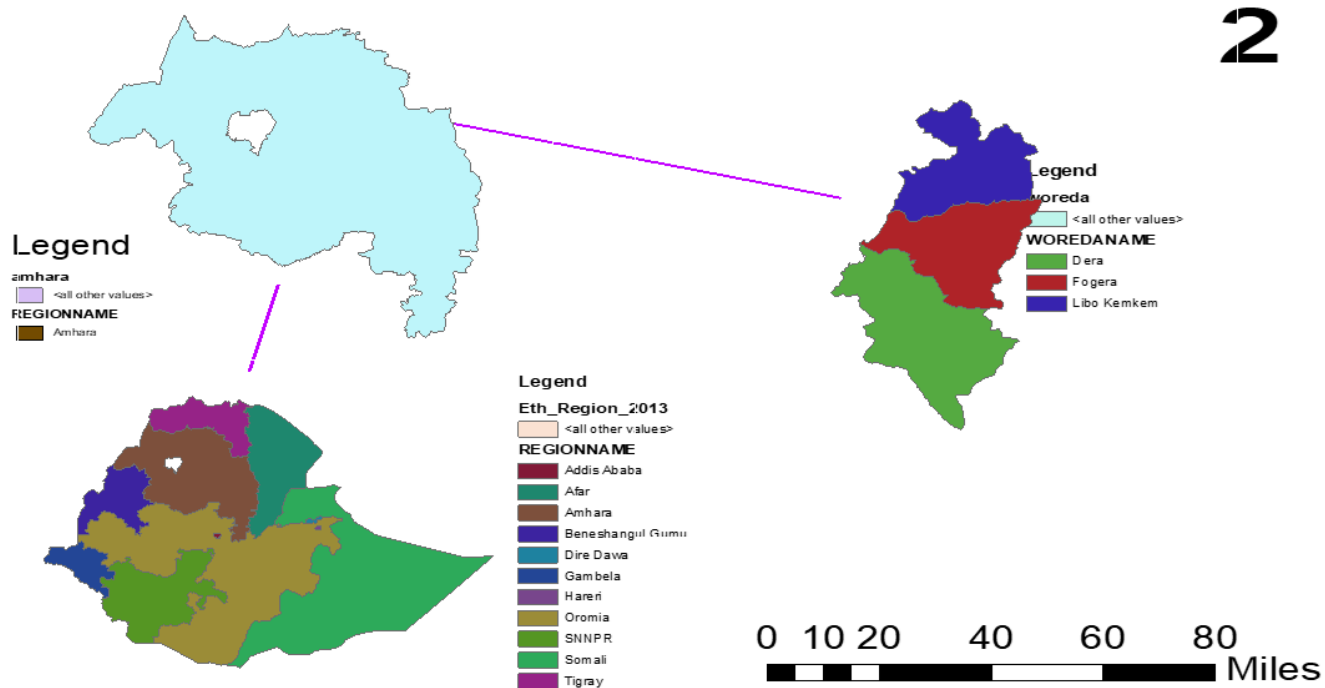


Figure 1

Study area

Source: own elaboration

The concentration of elements in Onion samples in Fogrea, Libokemkem and Derahamosit respectively

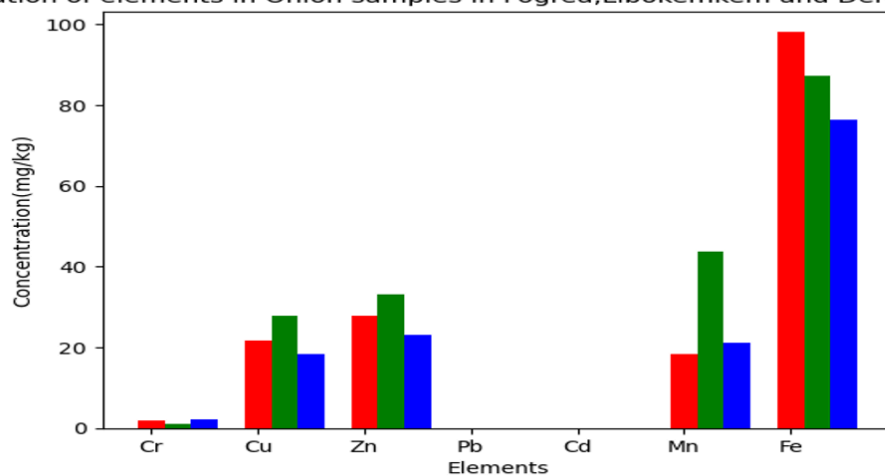


Figure 2

the concentration of onion samples

Source own elaboration

The concentration of elements in Rice samples in Fogrea,Libokemkem and Derahamosit respectively

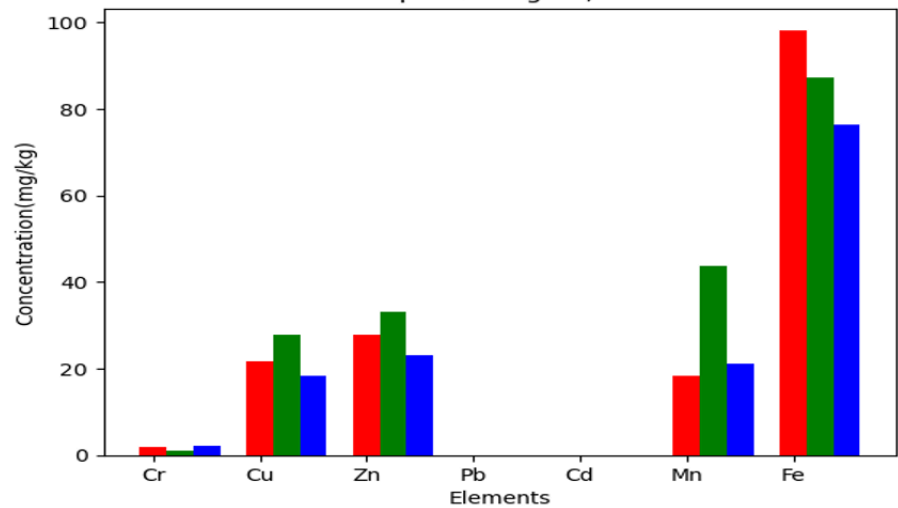


Figure 3

The concentration of rice samples.

Source: own elaboration

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