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A Systematic Review of Heavy Metals in Irrigation Water and Their Effects on Agricultural Soil Quality and Crop Production in Ghana

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Abstract

This study examines the impacts of heavy metals in irrigation water on soil quality and crop productivity in Ghana. Data was synthesized from 41 studies across 10 study areas spanning seven regions in Ghana. 10 heavy metals were identified from the synthetized data, namely, cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), manganese (Mn), zinc (Zn), copper (Cu), cobalt (Co), nickel (Ni), iron (Fe) and chromium (Cr). The synthesized data revealed that certain regions such as Upper East, Ashanti and Ahafo exhibits elevated cadmium level in soil and the western region showed high concentrations of Hg, As, Pb, and Cu exceeding WHO limits in irrigation water. Due to their economic importance and susceptibility to metal contamination, the analysis of the effects of these metals on crop productivity focused on maize and leafy vegetables. The findings show that metals such as As, Ni, and Cu, in irrigation water significantly affect soil metal concentration but do not affect crop productivity, but Hg, Zn, Pb, and Co rather influence crop yield. Interestingly, while Hg and Pb reduce yield in leafy vegetables, they positively affect maize productivity, highlighting the potential for tailored crop selection based on soil metal concentration to improve Agricultural outcomes.

Keywords

Agricultural Impacts, Crop Yield, Food Safety, Heavy Metals, Irrigation Water, Soil Quality

1. Introduction

Background and Rational of Study

The contamination of water bodies by heavy metals poses a significant threat to the sustainability of agriculture, especially in regions that rely heavily on these water sources for irrigation (Balkhair & Ashraf, 2016). Agricultural lands near mining and industrial areas in Ghana are constantly exposed to heavy metals which potentially affect soil health and crop productivity (Hadzi et al., 2019; Kumi et al., 2023). The aim of this systematic review is to synthesize existing research on heavy metals concentration in irrigation waterbodies and how they impact on agricultural soil quality and crop production in Ghana.

Currently, there is a growing environmental concern regarding heavy metal contamination in water bodies in Ghana, particularly due to activities including mining, industrial effluents and improper waste disposal (Boateng et al., 2019). Damoah (2013), Obiri (2018) indicate that water bodies near mining areas have elevated levels of heavy metals, exceeding World Health Organization (WHO) safe limits. Many farmers, however, rely on these contaminated water sources for irrigation (Lente et al., 2014). Heavy metal accumulation on agricultural soil reduces soil fertility and crop yield and poses a long-term risk to food safety and human health (Alengebawy et al., 2021). The agriculture sector employs about 45% of Ghana's population (Ankrah et al., 2020), hence a reduction in soil quality and crop yield will directly impact national food security and the country's economy. This study therefore aims to address the increasing concerns of heavy metal contamination of water bodies and its effects on agriculture in Ghana.

It is critical therefore to evaluate the effects of heavy metals in water bodies on agricultural soil quality and crop production in Ghana. Ghana heavily relies on the agriculture sector, which contributes about 20% to its GDP (Enu, 2014; Owusu et al., 2020). However, heavy metals such as mercury, lead, cadmium and arsenic, have been found in high concentrations in key agricultural towns such as Obuasi and Tarkwa (Gyamfi et al., 2019; Obiri-Nyarko et al., 2024). Studies such as (Osafo, 2011; Koranteng, 2019; Ankamah, 2022) have reported soil contamination levels in these areas to have exceeded permissible limits for agriculture purposes.

There is no doubt that there is a widespread knowledge of heavy metals contamination in mining regions in Ghana, however, when it comes to a localized and comprehensive study which focuses on the effects of these contaminants on Agricultural productivity, there is a significant Gap. Much of available research, including, (Bempah & Ewusi, 2016; Frimpong & Koranteng, 2019; Tay et al., 2019) tends to focus more on the impacts of heavy metals on environmental pollution or human health, with only limited studies providing detailed analyses of how heavy metal contamination directly affect soil quality, crop growth and overall agricultural productivity in Ghana. The aim of this systematic review is to consolidate existing research into how metal bioaccumulation in soil could lead to food productivity and safety concerns, especially in the context of smallholder farming systems in Ghana.

For this systematic review, the primary aim is to address the increasing concerns of heavy metal contamination of water bodies and its effects on agriculture in Ghana. The specific objectives include.

- To identify and assess the levels of heavy metal contamination in water bodies used for irrigation in agricultural areas in Ghana
- To evaluate the effects of heavy metal contamination in irrigated water on soil composition, fertility, health and overall soil quality.
- Analyze the impact of heavy metal contamination of soil quality on crop growth, yield and food safety.
- To explore potential mitigation strategies and agricultural practices capable of reducing negative effects of heavy metal contamination on soil quality and agricultural productivity.

These objectives have been set to guide this review in examining the extent of heavy metal pollution in agricultural areas and address its multifaceted impacts on agriculture while exploring opportunities for practical interventions.

The central research questions the review seeks to answer is, "how does heavy metal concentration in water bodies used for irrigation affect soil quality and crop yield in agricultural areas in Ghana". The PICO framework was used to define this research question. The PICO framework has been adopted by scholars like (Frampton et al., 2022; Methley et al., 2014; Scells et al., 2017), in quantitative research to help clarify the main components of the systematic review to ensure a focused and structured analysis. The specific research questions for the study include.

- What are the levels of heavy metal contamination in water bodies used for irrigation in agricultural areas in Ghana?
- How does heavy metal contamination in irrigated water affect soil composition, fertility, health and overall soil quality?
- How does heavy metal contamination of soil quality impact crop growth, yield and food safety?
- What mitigation strategies or agricultural practices can be adopted to reduce negative effects of heavy metal contamination on soil quality and agricultural productivity?

2. Methodology

2.1. Search Strategy

The systematic review adopted a comprehensive search strategy in identifying relevant studies on the effects of heavy metal contamination in irrigation water on soil quality for agriculture and crop production in Ghana. Two main databases were used, which include Scopus and Google Scholar with 33 and 89 articles retrieved from each respectively. Eleven (11) additional papers were identified through snowballing from references cited in relevant papers. The search string that was used across the databases included ("heavy AND metals AND concentration OR transfer AND in AND water AND bodies OR irrigation AND water

OR groundwater OR wastewater OR soil OR crops AND in AND Ghana").

2.2. Study Selection and Eligibility

With a focus on the study's objectives, the eligibility criteria focus on heavy metal contaminations in water used for irrigation, its impact on agricultural soil and crop production in Ghana. The inclusion criteria were 1) studies that focuses on heavy metal contamination in water bodies or water used for irrigation of agricultural lands in Ghana, 2) studies that assess the effects of heavy metals on soil quality, food safety and crop yield, 3) Articles published in peer-reviewed journals between years 2000 and 2024. The exclusion criteria also included 1) studies that does not address the agricultural impacts of heavy metals specifically or studies that focuses solely on non-agricultural sectors; 2) research conducted outside Ghana; 3) studies with insufficient data on heavy metal concentrations.

2.3. Data Extraction

The data extraction process followed the PRISMA framework. The PRISMA framework has been widely recommended and used by a lot of researchers such as (Mengistu, 2021; Page et al., 2021; Ravanipour et al., 2021; Shamseer et al., 2015) in conducting systematic reviews. **Figure 1** indicates the PRISMA flow diagram which provides a clear flow of how the various studies used in this study were identified, screened and included in the final analysis. Adopting the PRISMA framework indicates that the review process was both systematic and reproducible.

A total of 133 papers were identified for this study from Scopus, Google Scholar and snowballing from reference lists of relevant studies. Eighteen (18) duplicates were removed, hence reducing the number of studies to 115. The 115 studies were then screened through title and abstract review to access the relevance of each to the research objectives, of which 61 papers were excluded since they did not focus specifically on the effects of heavy metals in irrigation water on agriculture, soil quality or crop yield in Ghana. The 54 remaining papers were set for full-text retrieval and review, of which all 49 were successfully retrieved and reviewed.

Forty-nine (41) documents met the inclusion criteria after full text review and 8 were excluded for not meeting the criteria. The data from these studies were extracted and systematically organized to evaluate and understand heavy metals level in water bodies and their effects on soil health and crop production.

2.4. Quality Assessment

For this systematic review, the reliability and relevance of the included studies was very crucial, a comprehensive quality assessment was therefore conducted based on certain criteria. First, each study was evaluated for the potential of bias in research design, data collection and analysis. Studies that were rated low bias included those with clear methodologies, transparent reporting of data and well-defined research questions and objectives. Conversely, the studies with unclear

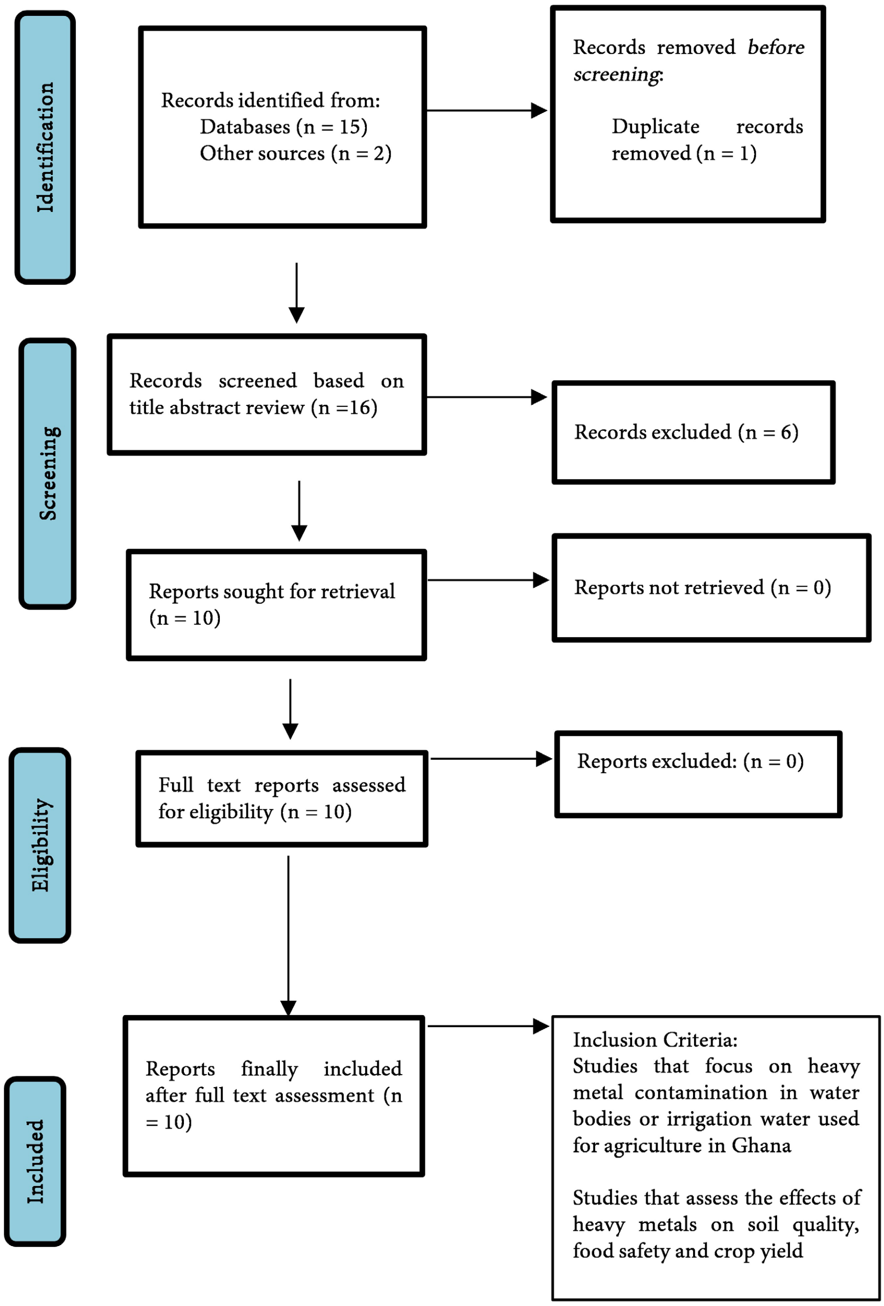

Figure 1. PRISMA flow diagram for systematic article review.

sampling methods, selective reporting or lack of control for confounding variables were rated potentially biased. Also, the appropriateness of the methodologies used to measure the various metal concentrations and soil quality were assessed. Studies that employed standardized testing methods and well-defined experimental controls were deemed high in quality, whereas studies with poorly defined sampling procedure or poor validation of analytical techniques were rated low quality. After the full test review of the 10 studies set for assessment, all the studies met the minimum threshold for quality and were included in the final synthesis. The assessment of quality was done to ensure that the conclusions drawn in this review are based on reliable and credible evidence.

2.5. Method of Data Analysis

The data used in this analysis was collated from 10 studies that measures heavy metal concentration in soil and water and some statistical reports of crop yield across multiple regions in Ghana. For this study, the null hypothesis was "there is no significant effect of heavy metal concentration in irrigation water on heavy metal concentration in soil and on crop yield". Due to the complexity of the study, 3 alternative hypotheses were formed. Alternative hypothesis 1: "there is a significant effect of heavy metal concentration in irrigation water on heavy metal concentration in soil and on crop yield", Alternative hypothesis 2: "there is a significant effect of heavy metal concentration in irrigation water on heavy metal concentration in soil but no significant correlation on crop yield", Alternative hypothesis 3: "there is no significant effect of heavy metal concentration in irrigation water on heavy metal concentration in soil but a significant correlation on crop yield". SPSS software was used to analyze the correlation and effects of heavy metal concentrations in irrigation water on soil contamination and on crop yield and test null hypothesis. Since regression analysis was used to analyze the effects, there was the need to ensure that all the variables are uniformly distributed. Therefore, logarithmic transformation was used to transform the various variables, including heavy metal concentration in irrigation water, heavy metal concentration in soil, average crop yield of leafy vegetables and average crop yield of maize to ensure normality. This transformation allowed for more accurate interpretation of the relationship between these variables.

3. Results

3.1. Overview of Study Area

The study synthesized studies on heavy metals in irrigation water and soils, to understand how heavy metals concentration in water for irrigation affect soil quality and productivity of crops. **Figure 2** indicates the various study areas across the country whose data was used for the analysis and **Figure 3** indicates the number of Articles the data was extracted per study area. Ghana has 3 main ecological Zones which supports different kinds of crops (Bellon et al., 2020), the distribution of the various studies across the country as shown in **Figure 2**, indicates a distribution of the data across the various zones. The Savanah zone covers the northern part of the country and is characterized by grassland and scattered trees, it has a dry climate and a single rainy season, making it suitable for maize, millet and sorghum production (Moomen et al., 2024; Yiridomoh et al., 2021). The forest Zone covers the central and parts of the southern parts of the country and receives higher rainfall hence supporting a wide range of vegetables and tree crops such as oil palm, cocoa, cashew (Ayivor et al., 2015). The third zone is the coastal Savanah zone which covers the southern coastal regions of the country. This zone has relatively dry and moderate rainfall, making it suitable for vegetables, rooted crops

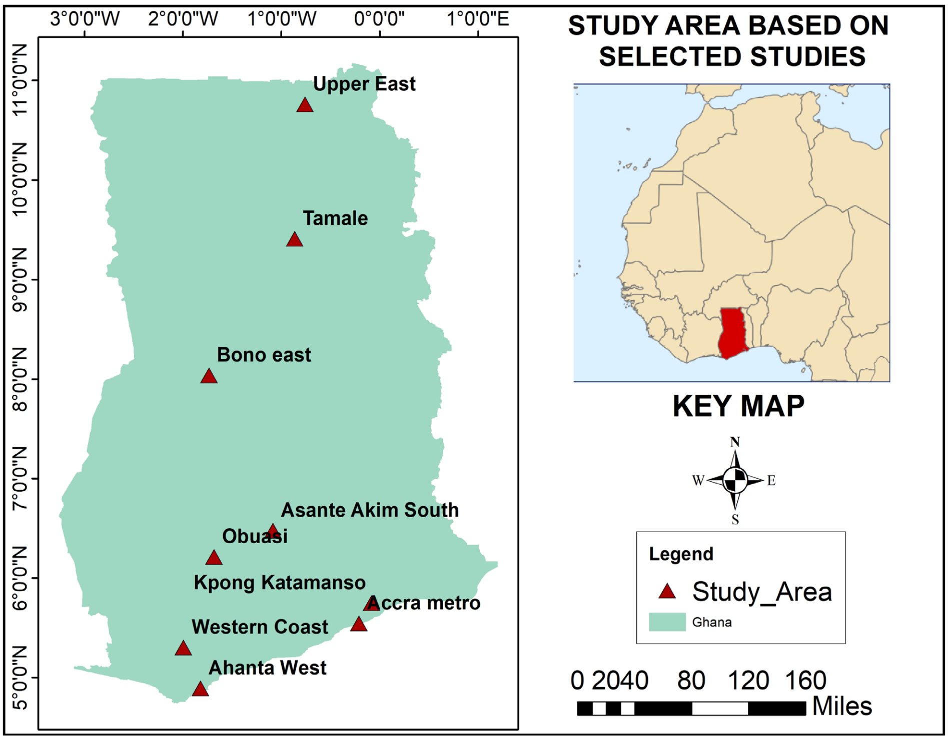

Figure 2. Map of study area.

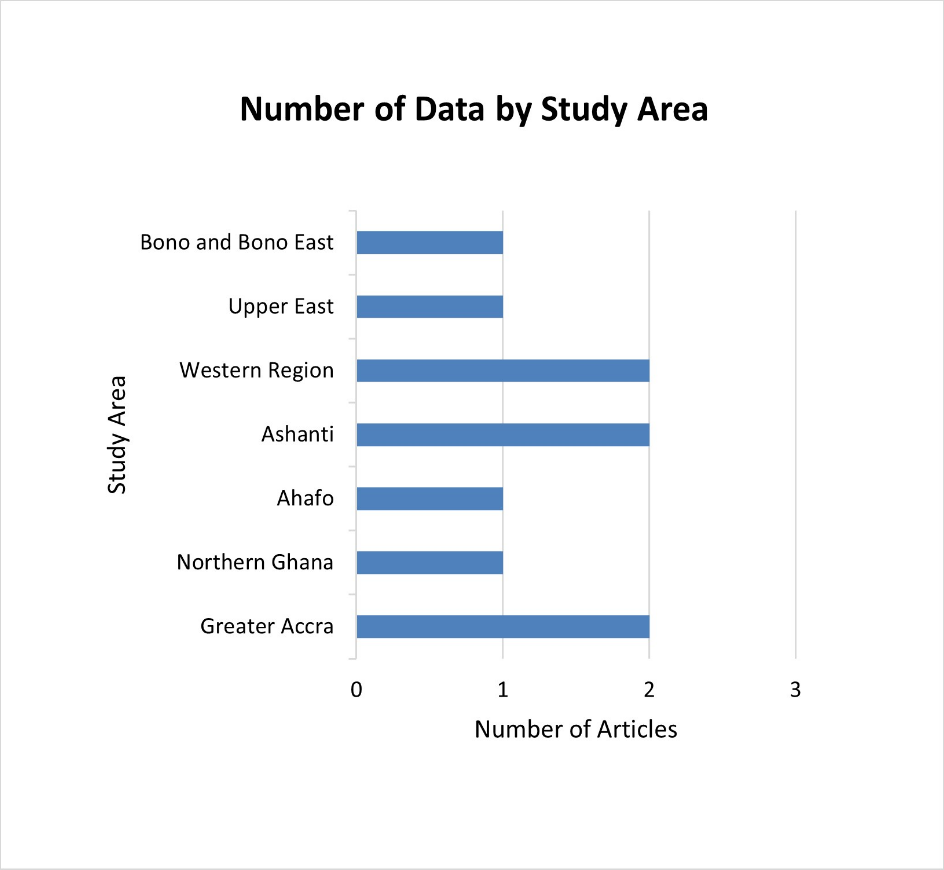

Figure 3. Distribution of article by study area.

like cassava and cereal crops like maize (Amoah, 2019).

Understanding the study area, including the various ecological characteristics is crucial, as there can be existing natural variations in soil and water metal concentrations; an example is the northern zone of Ghana, which has natural iron-rich soils. This can therefore influence baseline levels and inform accurate heavy metal contamination assessments.

3.2. Heavy Metal Concentration in Soil Across Regions

As presented in **Figure 4**, the various key heavy metals that were detected across the different study areas were cadmium (Cd), iron (Fe), Manganese (Mn) chromium (Cr), mercury (Hg), nickel (Ni), Zinc (Zn), Lead (Pb), Arsenic (As), Copper (Cu) and Cobalt (Co), with Pb, Zn, Cd, and Cu being the top 4 metals in terms of number of recordings in the various study areas.

Table 1 illustrates the concentration of each metal in soil across the various regions. From the table, there were significant variations in the concentration of metals in the soil across the study areas. In Accra Metropolitan for instance, the levels of cadmium (cd) were relatively low whereas iron (Fe) concentrations were considerably higher. The Kpong Katamanso area in the Greater Accra region also had similar concentrations as that of Accra metropolitan. In the Northern Region (Tamale), the concentration levels of iron were extremely high, while other metals such as lead, and copper had a minimal concentration level. Obuase Kokoteasua recorded the highest levels of arsenic, which is a depiction of the ongoing mining operations in the region. The Western Region also had elevated level of lead, whereas, Ahunta West also had high concentration of iron.

The result for the Upper East indicates heavy contamination of the soil, given the extreme concentration of chromium (Cr) and zinc. Ahafo Kenyase also recorded extreme levels of concentration of Arsenic and zinc, which are consistent with the mining activities of the area.

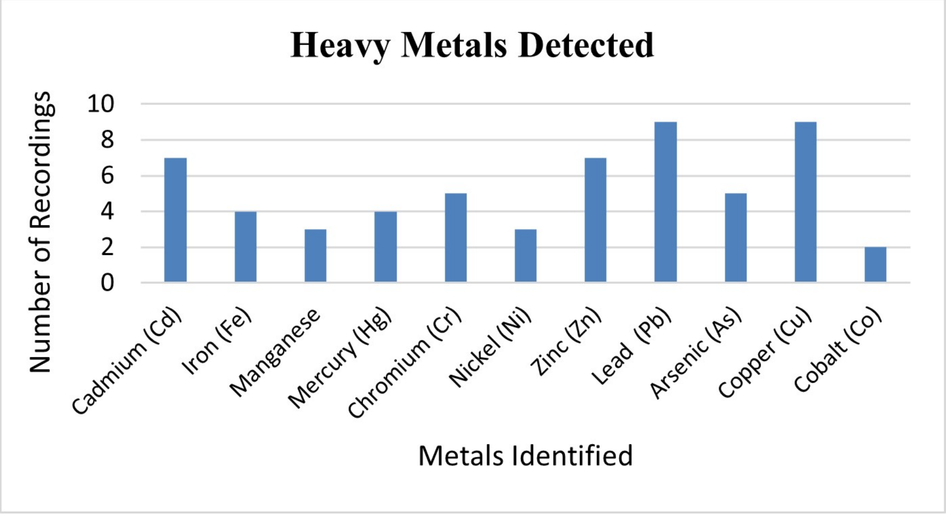

Figure 4. Heavy metals detected.

Table 1. Heavy metals concentration in soil across regions.

Study Area	Source	Metal Concentration in Soil (mg/kg)										
		Cadmium (Cd)	Iron (Fe)	Chromium (Cr)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Zinc (Zn)	Lead (Pb)	Arsenic (As)	Copper (Cu)	Cobalt (Co)
Accra Metropolitan	(Lente et al., 2012)	0.07 ± 0.17	164.38 ± 5.55	0.51 ± 1.53	39.39 ± 21.80	-	5.00 ± 2.48	6.03 ± 1.67	9.31 ± 2.23	-	7.21 ± 3.83	0.73 ± 1.28
Greater Accra (Kpong Katamanso)	(Fosu-Mensah et al., 2017)	0.04 ± 0.01	-	0.49 ± 1.03		-	4.09 ± 0.01	5.33 ± 1.00	9.37 ± 3.07	-	7.20 ± 0.00	1.30 ± 1.00
Northern Ghana (Tamale)	(Gyampo et al., 2012)	0.033 ± 0.00	181.9 ± 0.00	-	9.333 ± 0.00	-	-	-	0.052 ± 0.00		0.033 ± 0.00	-
Ashanti	(Sarpong et al., 2022)	4.29 ± 0.90		-		0.004 ± 0.00	-	-	2.93 ± 0.53	2.37 ± 0.56	8.87 ± 2.23	-
Ashanti (Kokoteasua-Obuasi)	(Gyamfi et al., 2019)	-	28064.5 ± 0.00	-	319.25 ± 0.00	-	-	56.1 ± 0.00	24.5 ± 0.00	627.6 ± 0.00	23.05 ± 0.00	-
Western Region (Western Coast)	(Fosu-Mensah et al., 2017)	-	-	-	-	0.02 ± 0.01		39.49 ± 14.36	21.59 ± 3.88	2.06 ± 1.27	6.55 ± 4.75	-
Western Region (Ahunta West)	(Affum et al., 2020)	0.02 ± 0.00	303.38 ± 0.01	1.95 ± 0.00		0.044 ± 0.01	0.051 ± 0.00	3.25 ± 0.00	-	-	-	-
Upper East	(Essel, 2017)	3.2	-	384.5	-	-	-	214.9	37.0	-	28.35	-
Bono and Bono East	(Amankwah et al., 2023)	-	-	0.389	-	-	-	-	2.209	0.201	0.139	-
Ahafo (Kenyase)	(Kumi et al., 2023)	0.567 ± 0.21	-	-	-	0.342 ± 0.12		20.500 ± 10.55	10.223 ± .10	4.013 ± 1.00	17.545 ± 8.43	-
WHO Permissible Limits	(Mensah et al., 2009)	**0.3 - 3**	**unspecified**	**100**	**unspecified**	**0.3**	**50**	**300**	**100**	**20**	**100**	**8**

3.3. Heavy Metal Concentration in Irrigation Water

Just like the heavy metal concentrations in soil across the different study areas, the concentration of heavy metals in irrigation water also varied significantly as shown in **Table 2**. In the Accra metropolitan area, metal concentration was generally low, indicating relatively low contamination levels, especially as each metal contamination was below WHO permissible limits. In the Kpong Katamanso Area, the concentration of Pb was slightly more than WHO permissible limits. However, in the Northern region (Tamale), the situation was different, with higher concentrations that are beyond WHO permissible limits in Cd, Fe and Cr, hence indicating a potential contamination of agricultural soil when used for irrigation (Bampoe et al., 2023).

Cd and Pb levels in the Ashanti region were all higher than WHO permissible limits and in Obuasi Kokoteasua, Fe and Cr were also slightly higher than WHO permissible limits, hence suggesting the influence of nearby industrial activities. A significant contamination levels of Hg, Zn, Pb and Cu were also recorded in the Western region (Western Coast). The levels of metal concentrations on the western coast indicate serious pollution concerns, potentially stemming industrial discharges (Amengor & Kwasi Amengor, 2024). Cr concentrations were also notably high in the Bono and Bono East area, with high Fe levels in the Ahafo Kenyase area.

Table 2. Heavy metals concentration in irrigation water across regions.

Study Area	**Source**	**Metal Concentration in Irrigation Water (L/kg)**									
		Cadmium (Cd)	Iron (Fe)	Chromium (Cr)	Manganese (Mn)	Mercury (Hg)	Nickel (Ni)	Zinc (Zn)	Lead (Pb)	Arsenic (As)	Copper (Cu)
Accra Metropolitan	(Lente et al., 2012)	BDL	0.67 ± 0.09	BDL	0.78 ± 0.73		0.06 ± 0.03	0.14 ± 0.05	0.08 ± 0.04		0.06 ± 0.01
Greater Accra (Kpong Katamanso)	(Fosu-Mensah et al., 2017)						0.13 ± 0.01	0.13 ± 0.11	0.12 ± 0.02		0.07 ± 0.01
Northern Ghana (Tamale)	(Gyampo et al., 2012)	0.027 ± 0.000	0.3015 ± 0.000		0.254 ± 0.000			0.0149 ± 0.000	0.021 ± 0.000		0.086 ± 0.000
Ashanti	(Sakyi et al., 2022)	0.1					0.06		0.5	0.09	
Ashanti (Kokoteasua-Obuasi)	(Gyamfi et al., 2019)		0.44		0.245			0.048	0.028	0.105	0.038
Western Region (Western Coast)	(Fosu-Mensah et al., 2017)					3.17 ± 0.64		9.88 ± 0.79	91.74 ± 6.17	2.70 ± 1.2	17.47 ± 1.14
Western Region (Ahunta West)	(Affum et al., 2020)	0.016 ± 0.000	2.217 ± 0.005	0.0007 ± 0.000		0.008 ± 0.000	0.0009 ± 0.000	0.0009 ± 0.000			
Upper East	(Asare-Donkor & Adimado, 2020)	0	0.986		0.03			0.094	0.041	0.073	
Bono and Bono East	(Amankwah et al., 2023)			0.45 ± 0.000					0.5 ± 0.000	0.45 ± 0.000	0.24 ± 0.000
Ahafo-Kenyase	(Kumi et al., 2023)	0.000 ± 0.000	3.710 ± 2.900		0.360 ± 0.660	0.023 ±.2.140			0.001 ± 0.002	0.003 ± 0.004	0.002 ± 0.001
WHO Permissible Limits	(Mensah et al., 2009)	**0.01**	**5.0**	**0.1**	**0.2**	**0.001**	**0.2**	**2.0**	**0.1**	**0.1**	**0.2**

Table 3. Average vegetable and maize yield of selected regions in Ghana.

Area	**Source**	**Average Crop Yield (Metric tons/hecter)**	
		Leafy Vegetables	**Maize**
Accra Metropolitan	(MoFA, 2021; GSA, 2020)	10.00	2.40
Greater Accra (Kpong Katamanso)	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	10.00	2.30
Northern Ghana (Tamale)	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	9.00	2.10
Ashanti	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	11.00	2.30
Ashanti (Kokoteasua-Obuasi)	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	10.00	2.20
Western Region (Western Coast)	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	10.00	2.00
Western Region (Ahunta West)	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	10.00	2.10
Upper East	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	6.00	1.80
Bono and Bono East	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	10.00	2.50
Ahafo-Kenyase	(MoFA, 2021; Assibey-Yeboah & Koomen, 2022)	10.00	2.00

3.4. Average Crop Yield of Selected Regions in Ghana

According to (MoFA Production Figures, 2016), one of the major crops produced and consumed in the 10 study areas is maize, which makes it an appropriate commodity to consider for this study. Also, research by Sandeep et al. (2019); Wang et al. (2017) highlights that heavy metal concentration in water and soil have a greater impact on leavy vegetables and maize due to their high metal absorption rate. This underscores the importance of analyzing the effects of heavy metals concentrations in water and soil on maize and vegetables. **Table 3** indicates the average crop yield for leafy vegetables and maize across the various study areas, with the highest yield of leafy vegetables (11 metric tons/ha) is in the Ashanti region, with the lowest in upper east region (6 metric tons/ha). The Bono and Bono region recorded the highest yield in maize (2.5 metric tons/ha), whereas the lowest yield in maize was recorded in Upper East region (1.8 metric tons/ha).

4. Analysis and Discussions

4.1. Introduction

The results highlighted in session three provide a comprehensive overview of heavy metal concentrations in irrigation water and soils across the study areas as well as the various crop yields that are recorded in these study areas. This session now explores their interconnectedness, thus assessing how metal concentrations in irrigation water affects metal concentration in soil and its potential impacts on crop yield.

From both **Table 1** and **Table 2**, there are observed variations in both heavy metal concentration in irrigated water and soil across the various study areas. This highlights potential significant correlations between water quality and soil contamination that may be primarily driven by irrigation practices. In the Accra Metropolitan area, although the irrigation water showed a detectable iron level of 0.67 mg/L, the levels are not enough to contribute to the high levels of iron in the soil (164.38 mg/kg). This suggests that other factors such as urban runoff, industrial emissions and corrosion of infrastructure are potentially contributing to the elevated iron levels in the soil. This aligns with the findings by (Fianko & Korankye, 2020), who indicated that increased soil metal concentrations are often experienced in urban areas due factors such as urban runoffs carrying corroded materials.

In tamale however, the concentration of cadmium in the soil could be attributed to the high concentration of cadmium (0.027) in the irrigation water. As indicated by (Kubier et al., 2019), the presence of cadmium in water used in irrigation can accumulate in soils, leading to the present of cadmium in soils. The high concentration of iron in the soil, however, may be attributed to other factors such as the geology of the northern region. According to Nartey (1997), the geology of the northern region naturally makes the soil iron-rich, which aligns with the elevated iron levels in the tamale area. This highlights the importance of monitoring water quality when developing strategies to prevent soil contamination.

Although the concentration of zinc, lead and copper do not exceed permissible limits in the western coast area, their presence and high levels in soil could be attributed to the elevated levels of these metals in the irrigation water. The concentrations of these metals exceed the WHO permissible limits in irrigated water for the western coast, which according to (Hadjipanagiotou et al., 2020; Chopra et al., 2009), can severely Impact soil quality and crop yields.

In Kokoteasua-Obuasi, although the arsenic concentration in the water (0.105

mg/L) was beyond WHO permissible limit, the high concentration of arsenic in the soil (627.6 ± 0.00) could be attributed to the mining activities in the area. (Banson et al., 2020) highlights that the arsenic distribution in soil and water in Obuasi can be attributed to the mining operations in the area. In contrast, areas such as Bono and Bono East, as well as Upper East demonstrated a relatively lower concentration in most metals in both water and soil in relation to WHO's Permissible limits. The low levels of metal concentration could be attributed to the low level of industrial activities in these areas, hence aligning with the findings of (Fosu-Mensah et al., 2017; Obiri-Nyarko et al., 2024) indicating that industrial activities contribute significantly to the accumulation of heavy metals in soil and water bodies.

Despite most metals not exceeding the WHO permissible limits, the level of chromium concentrations in Upper East is alarming, this exceeds the WHO permissible limit by 284.5 mg/kg. These elevated levels of chromium can be attributed to the use of chromium containing pesticides and fertilizers, as well as improper solid waste disposal (Agbeshie et al., 2020; Ertani et al., 2017; Fagariba et al., 2018; Prasad et al., 2021). These findings overall highlight the need for further investigation into the correlation between heavy metal concentrations in irrigation water and agriculture soil, to particularly assess the long-term impacts of these metal concentrations on crop yield and food safety.

4.2. Correlation and Effects between Heavy Metals in Irrigation Water and Soil

Table 4 depicts a correlation analysis between heavy metal concentrations in irrigation water and soil with the help of SPSS. With a Pearson correlation coefficient of 0.241 ($p = 0.110$), the correlation analysis illustrates a weak positive relationship. Although there is some degree of correlation, statistically the relationship is not significant, suggesting that heavy metal in irrigation water may not be the only source of soil contamination across the study areas. This weak correlation aligns with findings from previous studies including (Emmanuel, et al., 2014; Meuser, 2010), which highlights that soil contamination could be attributed to other factors such as industrial waste, urban and agricultural runoffs as well as atmospheric deposition.

Table 4. Correlation analysis of heavy metal concentration in irrigation water and soil.

Correlations			
		Log10ConcentrationinWater	Log10ConcentrationinSoil
Log10ConcentrationinWater	Pearson Correlation	1	0.241
	Sig. (2-tailed)		0.110
	N	58	45
Log10ConcentrationinSoil	Pearson Correlation	0.241	1
	Sig. (2-tailed)	0.110	
	N	45	52

Table 5 also illustrates a regression analysis between heavy metal concentrations in irrigation water and soil. Although Table 4 indicated a weak correlation, it is important to analyze the effects of the concentration of the individual metals on the soil. Table 5 illustrates a strong correlation between metals such as Arsenic (As), Nickel (Ni) and Copper (Cu) in irrigation water on the metal concentrations in the soil.

Among these metals, (As) has the highest standardized coefficient of (1.134), indicating that, a unit change in arsenic in irrigation water results in a 1.134 increase in metal concentration of the soil. Also, with a standardized coefficient of 0.307 in (Ni), it indicates that a unit increase in nickel concentration in irrigation water results in a 0.307 increase in metal concentration of the soil. Similarly, the results also suggest that a unit increase in (Cu) results in a 0.174 increase in the metal concentration of the soil. A p-value (sig.) for all metals less than 0.05, indicates that the effects are significant for all the metals.

These findings therefore align with other studies such as (Ebo Yahans Amuah et al., 2022; Fianko & Korankye, 2020), which identified that irrigation water contributes to soil contamination in agricultural lands. Similarly, Gillispie et al., (2015); Natasha et al., (2021) also demonstrated in their research that the presents of metals such as arsenic and nickel in irrigation water accumulates in soil overtime, which can lead to elevated soil contamination. Other variables such as lead, mercury, cadmium etc., were excluded from the regression model because they do not significantly contribute to the heavy metal concentration in soil.

Table 5. Regression analysis.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	<0.00	<0.00

a. Predictors: (Constant), Water Copper (Cu), Water Nickel (Ni), Water Arsenic (As)

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	−1.705	0.000		<0.00	<0.00
	Water Nickel (Ni)	6.569	0.000	0.307	<0.00	<0.00
	Water Arsenic (As)	484.423	0.000	1.136	<0.00	<0.00
	Water Copper (Cu)	2.598	0.000	0.174	<0.00	<0.00

a. Dependent Variable: Log10ConcentrationinSoil

4.3. Effects of Heavy Metal Concentrations in Soil on Crop Yield

Having established that some metals in irrigation water can affect the accumulation of metals in soil, there is the need to analyze the effects of metal contamination in soil on crop yield. Table 6 and Table 7 illustrate a regression analysis between soil metal concentration and crop yield. From **Table 6**, metals such as manganese (Mn), mercury (Hg), zinc (Zn), lead (Pb) and cobalt (Co) significantly influence the crop yield of leafy vegetables.

The model excluded other metals such as cadmium (Cd), iron (Fe), chromium (Cr), arsenic (As), nickel (Ni) and copper (Cu), that had no significant influence on crop productivity. The standard coefficient indicates that only Zn and Co had a negative impact on the vegetable yield, thus, a unit increase in Zn and Co, reduce productivity of vegetable crops by 1.365 and 0.067 respectively. On the other hand, Mn, Hg and Pb had a positive influence on leafy vegetable crop yield. Mn increases crop yield by 0.075, while Pb and Hg increases crop yield by 0.434 and 0.029 respectively. This implies that, at low concentrations, certain heavy metals can stimulate the productivity of leafy vegetables, a phenomenon that was also observed in studies such as (DalCorso et al., 2014), indicating the micronutrients roles of metals such as Pb when present in trace amount. This data overall suggests that elevated concentrations of metals can adversely impact vegetable yield such as in the case of Zn.

Table 6. Model summary, metal concentration in soil on leafy vegetable crop yield.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000	1.000	<0.00	<0.00

a. Predictors: (Constant), Soil Cobalt (Co), Soil Manganese (Mn), Soil Zinc (Zn), Soil Mercury (Hg), Soil Lead (Pb).

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.993	0.000		<0.00	<0.00
	Soil Manganese (Mn)	5.276E−5	0.000	0.075	<0.00	<0.00
	Soil Mercury (Hg)	0.019	0.000	0.029	<0.00	<0.00
	Soil Zinc (Zn)	−0.002	0.000	−1.365	<0.00	<0.00
	Soil Lead (Pb)	0.003	0.000	0.434	<0.00	<0.00
	Soil Cobalt (Co)	−0.020	0.000	−0.067	<0.00	<0.00

a. Dependent Variable: Log10LeafyVergetables.

In the aspect of the effects of soil metal concentration on maize yield (**Table 7**), the result is somewhat reverse. Whereas Pb and Hg had a positive effect on leavy vegetables, they do have a negative effect on maize yield. The regression results as illustrated in **Table 7** indicate that a unit increase in Pb and Hg reduces maize yield by 1.241 and 0.442 respectively. This finding aligns with (Aslam et al., 2021; Zulfiqar et al., 2019), which also noted that lead (Pb) toxicity in soil can inhibit nutrient uptake in maize, leading to stunted growth, hence reducing productivity. Similarly, Muhammad et al. (2015); Tang et al. (2023), also links mercury contamination to impaired seed gemination and photosynthetic activities such as reduced chlorophyll production, which affect maize production. Also, whilst Zn and Co had negative effect on leafy vegetable yield, they have a positive effect on maze yield, hence suggesting that, while they may be stunt leavy vegetable production, at appropriate concentrations, they may serve as essential micronutrients that enhance maize production.

These findings underscore the need to carefully monitor and manage soil metal concentrations as a measure to prevent reduced agricultural productivity and ensure food safety and security. Also, the findings highlight the necessity of testing soil properties to determine the crops suitable for specific soils, as certain metals may be beneficial to one crop but toxic to another. These nuanced effects must therefore be considered in sustainable agricultural practices to optimize crop yield and maintain soil health.

Table 7. Model summary, metal concentration in soil on maize crop yield.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	1.000	<0.00	<0.00

a. Predictors: (Constant), Soil Cobalt (Co), Soil Manganese (Mn), Soil Zinc (Zn), Soil Mercury (Hg), Soil Lead (Pb)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	0.409	0.000		<0.00	<0.00
	Soil Manganese (Mn)	0.000	0.000	0.373	<0.00	<0.00
	Soil Mercury (Hg)	−0.172	0.000	−0.442	<0.00	<0.00
	Soil Zinc (Zn)	0.000	0.000	0.260	<0.00	<0.00
	Soil Lead (Pb)	−0.005	0.000	−1.214	<0.00	<0.00
	Soil Cobalt (Co)	0.016	0.000	0.089	<0.00	<0.00

a. Dependent Variable: Log10Maize.

4.4. Correlation between Heavy Metals in Irrigation Water, Soil, and Crop Yield

The analysis from session 3.5 of this chapter reveals a significant effect of metals such as arsenic, nickel and copper in irrigation water on their concentration in agricultural soils. This implies that irrigation water can serve as a primary pathway for such metals to accumulate in soils, hence contributing to their contamination levels. However, despite the correlation between irrigation water and soil contamination, section 3.6 illustrates that the metals that significantly affect crop yield, both positively and adversely are not arsenic, nickel and copper. Instead, metals such as lead, zinc, mercury and cobalt, which showed no significant impact on soil from irrigation water, were more likely to impact crop production.

These findings therefore suggest that while some heavy metal contamination in irrigation water directly influences soil contamination, its effect on crop yield is however indirect. The effect of metal contamination of agricultural soil on crop production is therefore more dependent on the soil's existing metal composition and the type of metal present, rather than irrigation water, which aligns with studies such as (Dikinya & Areola, 2010).

5. Conclusion and Recommendations

5.1. Conclusion

The findings of this study reveal significant variations in heavy metal concentrations across different regions in Ghana. Some metals such as arsenic (As), nickel (Ni) and Copper (Cu) found in irrigation water were found to have significant influence on metal concentration in soil, with (As), showing the highest impact. These metals, however, do not directly affect crop yield, instead, mercury (Hg), zinc (Zn), lead (Pb), cobalt (Co) and manganese (Mn) were the metals directly affecting crop yield. Since there are some significant effects of heavy metal concentration in irrigation water on heavy metal concentration in soil but there is no direct corresponding effect on crop yield, we reject null hypothesis, alternative hypothesis 1 and 3, instead we fail to reject alternative hypothesis 2.

The study also revealed that, whilst Pb and Hg may positively affect the yield of leafy vegetables at trace level, the same level negatively affects maize yield. Similarly, whereas Zn and Co positively affect maize yield at trace levels, the same level negatively affects yield in leafy vegetables. These findings therefore demonstrate that the same metal can have both positive and negative effects depending on crop type as well as concentration levels, hence emphasizing the complexity of the interaction between heavy metals in irrigation water, soil health and crop production. While several guidelines such as WHO's permissible limits provide guidelines against heavy metal toxicity, they are, however, generic and do not fully capture the variations in crop responses to these metals. Crop specific soil testing, therefore, remains essential to balance food safety with crop productivity, hence ensuring that the benefits of these metals are harnessed without jeopardizing food safety and human health.

5.2. Recommendations and Future Research Directions

With the presence of metals such as arsenic, nickel and copper significantly affecting metal concentrations in soil, there is an urgent need for the regular monitoring of the quality of water used for irrigation, especially in regions close to mining or industrial zones. This enables early detection of metal concentrations to guide appropriate intervention such as water treatment or the use of alternative sources to prevent further contamination of the soil.

Also, both farmers and district agricultural offices should consider conducting periodic soil tests to assess the metal concentrations and determine its suitability for different crops. This will enable farmers to tailor crop selection to soil metal composition to harness the benefits of these metals and ensure increased crop productivity while ensuring food safety.

Additionally, remediation strategies could be explored for regions that have high levels of metals that negatively affect crop yield and food safety. Techniques such as phytoremediation such as planting hyperaccumulator plants to absorb and remove the metals or soil amendment by adding materials such as lime, organic matter or phosphate to immobilize heavy metals or regulate the soil Ph to reduce metal uptake could be adopted to enhance soil health.

Based on the findings of this research, future research should focus on the long-term effects of trace metal accumulation and its impact on soil health and crop yield. This is because the research illustrated that while some metals are beneficial to crop yield at low concentrations, they may become toxic at certain concentrations. Therefore, future studies should define the limits at which heavy metals transition from being beneficial to harmful or toxic contaminants.

Identifying these thresholds will help establish new guidelines for sustainable agriculture that ensures that metal concentrations remain within safe limits for both crops and human consumption.

Also, future studies should investigate the synergic or interactive effects of multiple metals. While there is existing research that examines the effects of individual metals on water, soil and crop productivity, these metals in water and soil coexist and their combination in a particular soil or water could result in a different effect on crops. Future studies could explore the synergic or antagonistic interactions between multiple metals and how different combinations of metals could contaminate soil or reduce crop productivity.

Additionally, having established that irrigation water can transfer metals to soil, more research is therefore needed to understand the direct pathways of these metal transfers, thus, whether different irrigation practices have different effect on metal transfer. Future studies should therefore assess how different irrigation techniques such as drip irrigation versus surface irrigation affect metal deposition in soil, and how the different techniques affect metal deposition in crops. Research into this could help develop the best agricultural practices that minimize heavy metal contamination of soil and crops through water management.

These research directions would not only provide a more comprehensive approach to managing soil and irrigation water quality but would also ensure sustainable crop production while safeguarding both human and environmental health.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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