# Unraveling the Nexus: Exploring the Influence of Heavy Metals in Irrigation Water on Vegetable Quality and Human Health

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**Abstract**

*The rising global population necessitates increased agricultural productivity to meet the growing demand for edible vegetables. Water scarcity has driven many farmers to irrigate crops with alternative water sources, including heavy metal-contaminated rivers. The environmental pollution and toxicological risks posed by heavy metals, particularly their tendency to bioaccumulate in human tissues, are well documented. Consequently, contamination of edible vegetables and agricultural soils has become a critical global environmental concern. This study assessed the impact of heavy metals on vegetable quality and human health risks in River Nyam, a mining-affected area in Obuasi Municipality, Ghana. Water samples from the river and selected edible vegetables were collected and analyzed during both the wet season (June – July) and dry season (November – December). Statistical analyses were performed and standardized indices such as total hazard quotient (THQ), and hazard index (HI) were computed based on the concentrations of heavy metals in the vegetables. Results revealed spatial variations in heavy metals concentration in River Nyam's water across different sampling points. Concentrations of Zn, Mn, Cr and Pb in the vegetables were within permissible limits, while levels of Fe, Co, As, Cd, Cu, and Hg exceeded the acceptable limits. Most vegetables exhibited significant heavy metal contamination, and the calculated hazard index values (HI > 1) indicated potential risks for consumers. Overall, the study underscored the unsuitability of River Nyam's water for agricultural irrigation due to its detrimental effects on vegetable quality and consumer health. The study also advocates strengthened water resources protection measures and comprehensive consumer risk assessments to support evidence-based policy formulation and decision making.*

**Keywords:** *heavy metals, irrigation water, vegetable quality and human health*

## 1.0 INTRODUCTION

Freshwater demand for agricultural irrigation has risen globally in tandem with population growth, resulting in an increasing cost of this scarce resource (Mateo-Sagasta et al., 2015). Rising water scarcity is further exacerbated by urbanization, population explosion, and climate change (Kabange & Nkansah, 2015). Rapid urbanization has also created a high demand for infrastructure services such as water supply, wastewater management, and sanitation (Kabange, 2017). Farmers are therefore increasingly turning to alternative water sources, including wastewater and contaminated stream water, to meet irrigation needs (Keraita et al., 2003; Baldwin & Stwalley, 2022). However, surface water sources often contain unmonitored contaminants that pose serious health risks when used for agricultural purposes (Gbedemah et al., 2024). For instance, approximately 20 million hectares of land worldwide are regularly irrigated with contaminated stream water (Drechsel & Keraita, 2014; Abdallah & Mourad, 2021). The use of contaminated water in agriculture is often driven by its affordability and belief that it has minimal adverse effects on crop health and yield (Angelakis & Snyder, 2015). In addition to its low cost and perceived negligible impact on crop growth, the belief that it poses minimal public health risks further promotes its use (Angelakis & Snyder, 2015; Corato et al., 2024). Moreover, research suggests that wastewater and stream water can provide essential nutrients and organic matter beneficial to crop growth, making them attractive for irrigation (Oyeku & Eludoyin, 2010). However, Altarawnch (2021) argues that heavy metals can have detrimental health effects on all living things, including humans, when in high concentrations.

In Ghana, rapid urbanization and erratic rainfall patterns led to freshwater scarcity, compelling farmers to rely on contaminated water sources for vegetable production (Gbedemah et al., 2024). The urban expansion has also increased reliance on agriculture to meet the dietary needs of a growing population. However, the use of contaminated water raises concerns regarding soil fertility, crop quality, and human health. Anthropogenic activities such as mining, improper waste disposal, and unsustainable agricultural practices significantly contribute to water contamination (Nyairo et al., 2015; Dehkordi et al., 2024). In developing countries, water pollution is often characterized by uncollected waste, clogged open drains, and the use of beaches as solid waste dumpsites (Kabange, 2017), despite the potential of waste conversion to a resource. In the Obuasi Municipality of Ghana, for example, unregulated mining activities and inadequate waste management systems have led to the contamination of local water bodies, including the River Nyam (Aboka et al., 2018). The infiltration of heavy metals such as lead (Pb), chromium (Cr), nickel (Ni), mercury (Hg), and arsenic (As) alter the physico-chemical properties of water, posing significant risks to both aquatic life and human health. The use of such contaminated water in agriculture not only affects soil fertility but also crop quality and public health. Altered soil pH levels and reduced organic matter content due to contaminated irrigation water negatively impact crop growth and yield (Meiramkulova et al., 2024). Heavy metals in contaminated water can accumulate in crops, posing long-term health risks to consumers (Balkhair & Ashraf, 2016; Mahmood & Malik, 2014).

Furthermore, the use of contaminated water for irrigation has broader environmental implications – osmosis and irrigation activities can exacerbate contamination levels in water bodies, potentially destabilizing aquatic ecosystems and threatening biodiversity (Adam et al., 2024). Consumption of farm vegetables irrigated with contaminated stream waters has been linked to chronic health conditions, including cardiovascular diseases and cancers, primarily due to the bioaccumulation of heavy metals in edible crops (Martinez-Castaneiras et al., 2025). Heavy metals toxicity is amply demonstrated when mercury in water is converted into methylmercury that accumulates in sediments and poses serious public health threats (Coetzee et al., 2020). Although some heavy metals occur naturally in the environment and are essential for plant growth and human survival in trace elements, their accumulation beyond acceptable limits is hazardous (Mitra et al., 2022). While Cr, Fe, Zn, Cu, and Mn are essential for human and animal growth since they promote enzymes activities, hormonal growth, protein transport at specific concentrations (Frydrych et al., 2023), others such as Hg, As, Pb and Cd are very poisonous and have no essential role in human and animal health, or plant growth (Angon et al., 2024).

The environmental pollution caused by heavy metals, driven by improper waste and effluent disposal, and accelerated by global population and economic growth, constitutes a pressing public health concern. Studies indicate that human exposure to heavy metals occurs primarily through the consumption of contaminated vegetables (approximately 90%), with the remaining 10% attributable to inhalation of polluted dust and dermal contact (Das et al., 2023; Khan et al., 2014). Therefore, the reliance on contaminated water for agricultural irrigation presents serious challenges to soil health, crop safety, human well-being, and the broader environment. The contamination of edible vegetables and soil by heavy metals has become a global environmental challenge. Although previous studies have investigated water pollution in the Obuasi Municipality, little attention has been given to the specific impact of using contaminated water. This study provides current data on the seasonal variability of heavy metals exposure through vegetables consumption in a relatively underreported site in Ghana. Additionally, by integrating site-specific water quality data with health risk assessment, it fills a critical gap in food safety and environmental risk research.

## 2.0 MATERIALS AND METHODS

This section outlines research design, data collection methods, sampling preparation procedures, analytical techniques, and approaches used for data analysis and health risk assessment.

### *2.1 Study area*

This study was conducted in Obuasi Municipality, a gold mining town situated in the Southwestern part of the Ashanti Region, Ghana. It lies between latitudes 5°35N and 5°65N, and longitudes 6°35'W and 6°90'W (Figure 1). Covering an area of approximately 220.7 km$^2$ with a population of 104,297, the municipality shares boundaries with Adansi North, Upper Denkyira District, Adansi South, and Amansie Central Districts (Ghana Statistical Service, 2021).

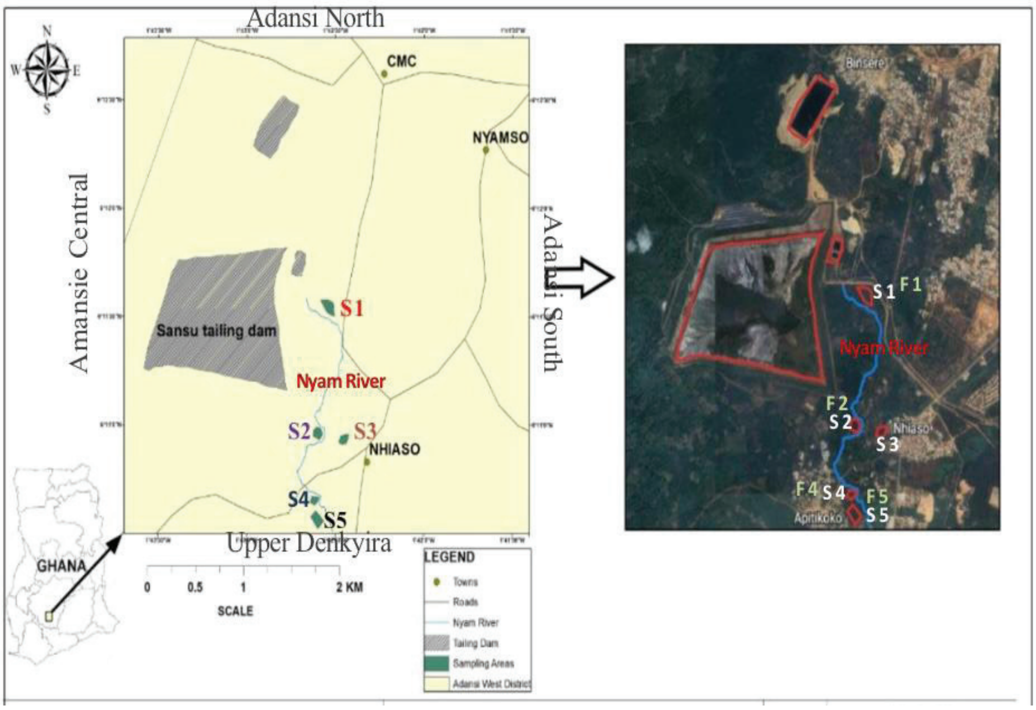


Figure 1: Map showing the study area (A) and sampling points (B)

Though the upper course of the River Nyam lies within a mountainous region, the broader landscape is drained by several streams and rivers, including the River Nyam itself. In its middle and lower courses, the river receives inflow from other water bodies, forming a single channel through multiple confluences. Embankment dams in the upper part of the municipality collect wastewater from gold-processing activities. Additionally, several abandoned galamsey pits and gold-processing sites are located along the riverbanks (Ghana Statistical Service, 2021).

### 2.2 Research design

The experimental research approach was employed to assess the quality and impact of heavy metal contamination in irrigation water on vegetables and associated human health risks.

### 2.3 Sample collection

Sampling and analyses were conducted following the Standard Methods for the Examination of Water and Wastewater samples (APHA, 2005). River Nyam was selected due to its exposure to illegal mining activities and proximity to buffer dams storing mining effluents. Sampling sites included major water abstraction points used for irrigation. Vegetable samples, tomato (*Solanum lycopersicum(current)*), okra (*Hibiscus esculentus*), and cabbage (*Brassica oleracea*) were randomly collected from farms along the river.

#### 2.3.1 Water sampling and preparation

A total of 48 water samples were collected from five (5) irrigation points along River Nyam during both the dry (November – December) and wet (June – July) seasons, accounting for seasonal variability in water quality. Control samples were taken about 500 meters from the River Nyam using groundwater sources unexposed to mining. Samples were collected in sterile 1.5-liter high-density polyethylene (HDPE) plastic bottles, pre-washed with concentrated nitric acid and distilled water. Each bottle was rinsed with site-specific water before collecting to prevent contamination. The samples were properly labeled with codes and collection dates, then stored and transported for laboratory analysis.

#### 2.3.2 Water digestion

Water samples were acidified with 5 mL of concentrated nitric acid ($HNO_3$) per litre to maintain a pH below 2, minimizing metal precipitation and adsorption onto container walls. Each sample was homogenized, and 50 mL was transferred into pre-labelled digestion tubes. A mixture of 10 mL of $HNO_3$, 3 mL perchloric acid ($HClO_3$), and 3 mL sulfuric acid ($H_2SO_4$) were added. The tubes were placed in a digestion block, and an additional 5 mL of $HNO_3$ was added, and the contents were heated to approximately 95°C until clear solutions were obtained. The digest was filtered using 0.45µm membranes and diluted to 50 mL with deionized water for analysis.

#### 2.3.3 Vegetable sampling and preparation

Edible portions of vegetables were randomly collected from farms irrigated with River Nyam water. Control samples were obtained from farms using clean water sources. All vegetables were washed with tap water and rinsed with deionized water to remove external contaminants. The samples were oven-dried at 65$^{o}$C for 72 hours to determine the dry weight, then pulverized, sieved for uniformity, and stored in clean containers at room temperature pending digestion.

### 2.3.4 Vegetable digestion

For digestion, 2.0 g of powdered vegetables were treated with a mixture of concentrated hydrochloric acid (HCl) and nitric acid ($HNO_3$). The mixture was heated from 80°C to 150°C on a digestion block until a clear solution (approximately 20 ml) was achieved. After cooling, the digests were filtered and transferred into 50 mL volumetric flasks and diluted with deionized water. All procedures were carried out in a fume hood for safety.

## 2.4 Heavy metals analysis

Heavy metals in water and vegetable samples were analyzed using a Thermo Scientific iCAP 6000 Series inductively coupled plasma optimal emission spectrometer (ICP – OES). The technique utilizes high-temperature plasma (6,000 – 10,000 K) to excite atoms in the sample, which then emit light at element-specific wavelengths and emission analyzed by a high-resolution optical system. The intensity of emissions at specific wavelengths corresponds to the concentration of each heavy metal.

## 2.5 Quality assurance

Quality assurance and control measures were rigorously followed. All workspaces were sterilized and conditioned, and only analytical-grade reagents were used. Samples were handled carefully to avoid contamination. Quality control procedures included the use of blanks, pre-digestion spikes, replicate measurements, and analysis of certified reference materials (CRMs). Results were validated by comparing them to certified values and ensuring procedural consistency. Instrument calibration and analytical performance were also monitored through periodic charting of key parameters.

## 2.6 Health risk assessment

Health risk assessment was conducted to evaluate the level of potential human health hazards associated with long-term consumption of vegetables contaminated with heavy metals (Mohammadi et al., 2019). Risks were classified as carcinogenic or non-carcinogenic (Wongsasuluk et al., 2014). Since vegetables accumulate toxic metals, the assessment focused on non-carcinogenic risks using the total hazard quotient (THQ) and hazard index (HI).

### 2.6.1 Total hazard quotient (THQ)

Quantitative evaluation of the possibility of systemic toxicity by a single element in a single exposure pathway was given by the target hazard quotient (THQ). THQ value below one (1) indicates no significant risk, while values above one (1) suggest possible adverse effects (Antoine et al., 2017). The THQ was computed with the following equation (Antoine et al., 2017; Gupta et al., 2022):

$$(\mathrm{THQ}) = \frac{C \times IR \times ED \times EF}{RfD \times BW \times AT} \times 0.001 \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. (1)}$$

where C is the concentration of each heavy metal in mg/kg dry weight, IR represents the ingestion rate in g/day, ED is the exposure duration = 70 years, EF is the exposure frequency = 365 days/year, RfD is the oral reference dose in mg/kg/day - Zn (0.3), Fe (0.7), Mn (0.014), Co (0.0003), Cr (0.003), As (0.0003), Cd (0.0005), Pb (0.0035), Cu (0.042), Hg (0.0001), BW represents the reference body weight = 70kg for adults, AT is average time of exposure for non-carcinogenic health risk = 25,550 days = 365days and conversion factor of $10^{-3}$ (Antoine et al., 2017; Gupta et al., 2022).

### 2.6.2 Hazard index (HI)

Evaluation of total potential for non-carcinogenic effects provided by many elements was made possible by integrating the calculated THQs for each element expressed as hazard index (HI). If the THQs for each target element in vegetable consumed are below one (1), the collective impact may lead to adverse non-carcinogenic health implications in the event of HI >1 (Altarawneh, 2021). The hazard index was computed using the following equation (Altarawneh, 2021; Gupta et al., 2022)):

$$\text{Hazard Index (HI)} = \sum_{N=1}^{i} THQ_n \qquad \text{… Equation 2}$$

### 2.7 Statistical analysis

Descriptive analysis was conducted using Microsoft Excel to interpret the results and facilitate data visualization, comparison, and summarization.

## 3.0 RESULTS AND DISCUSSION

Water samples from the Nyam River and edible vegetables irrigated with its water were analyzed for heavy metal concentrations. The results were evaluated against internationally accepted standards, and seasonal variations were assessed over the study period.

### 3.1 Heavy metals in River Nyam

Heavy metal analyses were conducted to determine concentrations in irrigation water, identify periods of peak contamination, and assess potential impacts on vegetable quality. The results were compared with permissible limits set by the WHO and the Ghana EPA and benchmarked against findings from similar studies in Ghana and other countries.

### 3.1.1 Concentration of Zinc

Zinc is essential for plant growth, playing critical roles in cellular metabolism, enzyme activation and maintaining ion homeostasis (Gupta et al., 2016). Its toxicity depends on the dose and route of exposure with mining and smelting identified as primary anthropogenic sources (Mitra et al., 2022). Zinc emissions into the environment largely originate from anthropogenic activities and affect both living organisms and ecosystems (Zhang et al., 2012). In this study, Zinc concentrations in the irrigation water ranged from 0.06 mg/L to 0.47 mg/L, remaining below both the Ghana EPA permissible limit of 0.5 mg/L and WHO standard of 0.35 – 2.0 mg/L (WHO, 2006). Comparable studies in Ghana reported even lower (< 0.001 mg/L) values, averages of (< 1.4 mg/L) (Affum et al., 2020; Dadebo & Gelaw, 2024). However, a study in Rivers State, Nigeria, found that all obtained results from a stream were above WHO drinking water requirements except Cu and Zn (Ntembaba et al., 2023). Although the values observed in this study are within safe limits, suboptimal Zinc levels may impair plant growth (Gupta et al., 2016).

### 3.1.2 Concentration of Iron (Fe)

Iron concentration ranged from 1.11 mg/L to 7.50 mg/L, with most sampling points within the WHO and Ghana EPA limits of 0.50 mg/L – 5.0 mg/L. Similar concentrations were found in Accra, Ghana (0.8 mg/L – 1.5 mg/L) (Lente et al., 2014), suggesting a regional pattern of safe iron levels, likely due to natural soil contributions (Doyi et al., 2018). However, peak values occurred during the dry (June at SP1, 6.6 mg/L) and wet seasons (November at SP3, 7.5 mg/L, possibly due to runoff from iron-rich terrains, highlighting seasonal influences.

### 3.1.3 Concentration of Manganese (Mn)

Manganese is naturally abundant yet a potentially toxic metal, depending on concentration and oxidation state (Mitra et al., 2022). Concentrations remained within the FAO recommended maximum limit of 0.2 mg/L (FAO, 2017), except at SP3 (0.12 mg/L) and SP 5 (0.20 mg/L) in the wet season and 0.008 mg/L at SP5 in the dry season. These results align with findings from studies in Southwestern Cameroon (mean: 0.155 mg/L) (Nkobe et al., 2024)which at times are above the maximum concentration levels recommended, are detrimental to the quality of the water, soil and crops (plant. While previous Ghanaian studies reported higher Mn levels (Lente et al., 2014), they concluded that such concentrations did not pose health or phytotoxic risks.

### 3.1.4 Concentration of Chromium (Cr)

Chromium (Cr) is toxic, carcinogenic and found in the environment as chromium (III), and chromium (IV) and (VII) (Mitra et al., 2022). Its concentrations ranged from 0.002 mg/L to 0.062 mg/L, significantly lower than WHO limit of 0.10 mg/L (WHO 2006) but within Ghana EPA limits. These findings align with chromium levels reported in irrigation water in Ghana (Lente et al., 2014) and India (Ahirwar et al., 2018). In contrast, however, elevated chromium levels were found in Adis Ababa, where industrial runoff increased chromium concentrations (Jin et al., 2023). The safe chromium levels in this study suggest minimal industrial influence on the Nyam River compared to heavily industrialized regions.

### 3.1.5 Concentration of Arsenic (As)

Arsenic (As) had concentrations from 0.014 mg/L to 0.039 mg/L which were within WHO and Ghana EPA acceptable limits of 0.10 mg/L. Khan et al. (2013) also found that As concentrations from 0.05 mg/L to 0.2 mg/L did not exhibit any phytotoxic symptoms other than biomass reduction in some cases. The significantly lower As levels in this study suggest reduced As leaching in the Nyam River catchment. However, continuous monitoring is necessary to prevent potential contamination through future activities.

### 3.1.6 Concentration of Lead (Pb)

Found in relatively small quantities in nature, lead is a non-biodegradable metal, toxic to human health when exposed to quantities that exceed permissible limits, and children are particularly at high risk of lead poisoning (Mitra et al., 2022). Lead concentration peaked at 0.12 mg/L, exceeding the WHO limit of 0.06 mg/L but within the Ghana EPA threshold of 0.1 mg/L. High Lead contamination in irrigation water was similarly reported in Nigeria (Oloruntoba et al., 2024). This study finding concurred with earlier published work in Ghana that found that lead (Pb) concentrations in vegetable products were harmless when below 0.08 mg/L (Osae et al., 2023). The higher Lead levels observed in this study might be attributed to industrial discharge or mining runoff that carried wastewater from the main treatment plant to the tailings dam, emphasizing the need for stringent waste management practices.

### 3.1.7 Concentration of Copper (Cu)

Copper is an important micronutrient for living organisms, and plays important roles in physiological functions such as photosynthesis, chlorophyll formation and protein-carbohydrate metabolism (Mitra et al., 2022). Copper concentrations were consistently below the WHO permissible limit of 0.2 mg/L, with the exception of sampled water SP 1 (0.24 mg/L) in November, a finding which corroborates a study in Kenya where copper levels ranged from 0.0034 mg/L – 0.0055 mg/L in irrigation water (Tomno et al., 2020). Another study in Akpor, Rivers State in Nigeria, where all obtained results from a stream were above WHO requirements for drinking water, except copper and zinc (Ntembaba et al., 2023). These findings also agree with an earlier study which discovered that irrigation water with significantly lower levels of copper (Cu) concentration was not toxic but could cause oxidative damage to cells and interfere with photosynthetic activities, leading to retarded crop growth and development (Giannakoula et al., 2021). Some studies in Ghana, however, reported slightly higher Copper concentrations, suggesting localized variations possibly influenced by soil composition and industrial activities.

### 3.1.8 Concentration of Mercury (Hg)

Mercury (Hg) is a hazardous widespread heavy metal and has recently been increasing in the atmosphere due to anthropogenic activities. In contact with aquatic sediments, Hg is converted into toxic methylmercury (Gworek et al., 2020). The highest Hg concentration was recorded in the dry season in December at SP 5 (0.031mg/L) while the concentrations in July at SP 5 was 0.027 mg/L, which slightly exceeded the WHO limit of 0.02 mg/L (WHO 2006). A similar study in the Greater Accra Metropolis of Ghana found mercury and faecal coliform concentrations in selected vegetables exceeded WHO permissible limits (Gbedemah et al., 2024). Though mercury released into the environment happens through natural sources such as soil or fertilizer farmers use, anthropogenic activities along the Densu river in Ghana was found to be the main source of heavy metals in vegetables (Gbedemah et al., 2024). Mercury concentrations observed in this study showed the influence of regional mining operations and emphasized the need for remediation measures to prevent bioaccumulation in crops. These findings were consistent with an earlier study which found that mercury (Hg) levels between 0.0002 mg/L and 0.008 mg/L were found in mining areas, and the crops may accumulate mercury over time, which is generally less harmful at that level (Li et al., 2023).

## 3.2 Hazard and health risk evaluation

As shown in Figure 2, the hazards and health risks associated with contaminated vegetable consumption were also assessed using target hazard quotient (THQ) and hazard indices (HI) with emphasis on heavy metals concentration levels in the vegetables. The results showed that the THQ value exceeded unity, except for Zn, Fe, Mn, Co, Cr, Pb, and Cu in the wet season and Zn, Fe, Mn, Cr, Pb, and Cu in the dry season. The HI for the targeted metals in the various vegetables from all the farms far exceeded the USEPA recommended threshold of HI $< 1$ with arsenic (As) levels contributing to extremely high values. Heavy metals concentrations were found in most vegetables, thereby exposing consumers to significant health risks. The alarming arsenic levels were due to the release and gradual arsenic accumulation effect over a period as it naturally occurred in crushed rocks and might be extracted as an impurity in metal ores during mining activities. Most of these contaminants could also be released into the environment and end up in the air, soil, and water bodies through weathering, oxidation, and erosion.

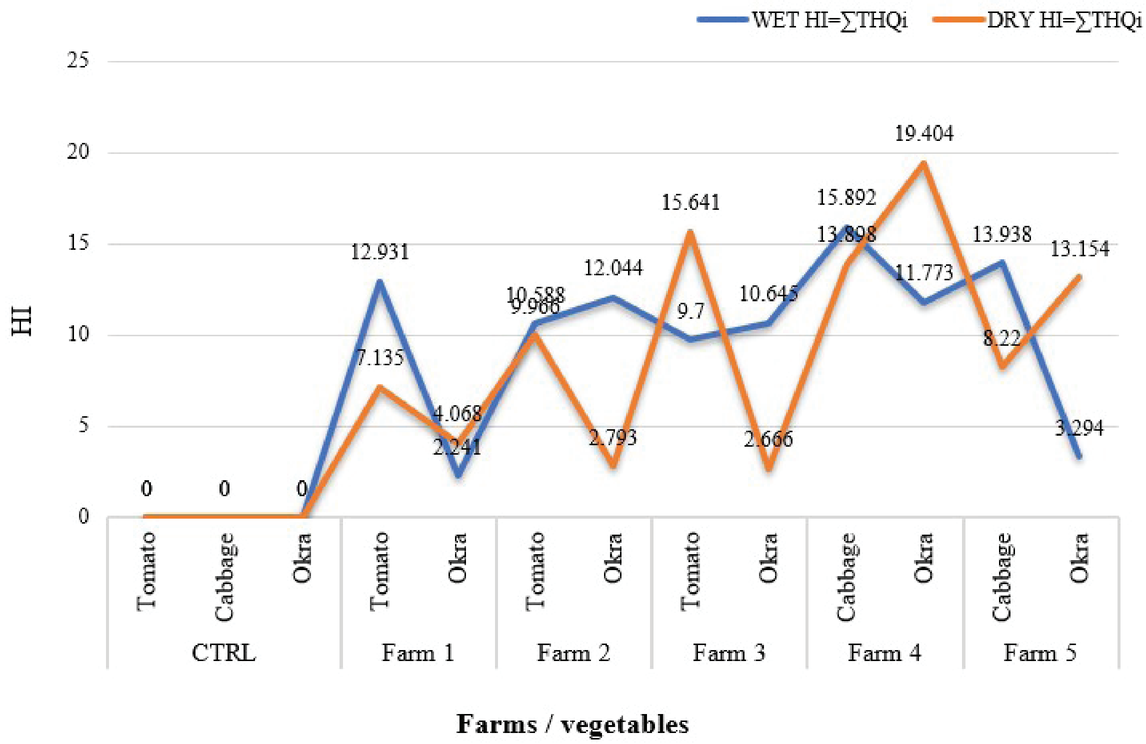


Figure 2: Hazard indices in the wet and dry seasons

On average, the wet season posed a higher risk to consumers based on the computed values compared to the dry season. While both seasons presented elevated exposure, vegetable consumption during the wet season posed a significantly higher health risk. This could be attributed to increased runoff, erosion, and mobilization of contaminants from the surrounding and agricultural areas during the rainy period. It is well documented that mining and exploration activities often contribute to elevated hazard index (HI) values in nearby water and food systems (Elumalai et al., 2017; Escobar-Segovia et al., 2021). Dietary intake assessment further revealed high levels of Pb and Cd accumulation in both children and adults, often exceeding tolerable thresholds (Ali et al., 2021). These findings highlight the importance of enforcing phytosanitary regulations, implementing systematic monitoring of irrigation resources, and adopting sustainable agricultural practices to safeguard public health.

## 4.0 CONCLUSIONS AND RECOMMENDATIONS

This study examined the concentration of heavy metals in irrigation water from the Nyam River and their uptake by vegetables grown along the riverbanks. The findings reveal a strong connection between irrigation practices using contaminated water and elevated metal accumulation in edible crops. Although some metal concentrations fell within internationally acceptable limits, others such as Pb, As, and Hg exceeded the WHO and Ghana EPA thresholds, especially during the wet season. The elevated levels of contaminants were primarily attributed to illegal mining activities, runoff from surrounding landscapes, and poor waste management along the riverbanks. Importantly, the sum of individual THQ values for all vegetables studied exceeded unity (HI > 1), indicating an unacceptable risk of non-carcinogenic health effects to both children and adult consumers. These findings align with other studies that highlight similar risks in peri-urban agricultural zones across Sub-Saharan Africa. Regular monitoring of soil and edible vegetables in the study area is strongly recommended to prevent further accumulation, likely to trigger significant non-carcinogenic health risks to consumers. To effectively protect public health, monitoring the presence of heavy metals in irrigation water, vegetables, and soil is strongly recommended. Finally, this study provides insights into the health risks associated with vegetable cultivation along the Nyam River and offers a foundation for evidence-based policy interventions, risk mitigation strategies, and future studies on metal bioaccumulation and exposure pathways in agricultural ecosystems in Ghana and beyond.

## CONFLICT OF INTEREST

The author declares no conflict of interest.

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