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Human Health Risks Due to Heavy Metals in Carica Papaya (Pawpaw) Irrigated with Waste Water from Abattoir in Ikwiriri Ward

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Abstract
Background: The abattoir wastes contain numerous pollutants, many of which can inhibit the growth of soil microorganisms, plants, animals, and negatively impact the entire ecosystem. Carica papaya grown around the Ikwiriri abattoir is widely consumed, yet data on heavy metal contamination from abattoir waste is limited.
Objective: To assess the levels of selected heavy metals (Cr, Cu, Pb, Cd, and Zn) in carica papaya fruits, and soils around the abattoir in Ikwiriri Ward.
Methods: This study measured selected heavy metals in papaya fruits and their soils using Atomic Absorption Spectroscopy equipped with a continuous flow of Vapour Generation Accessory (VGA).
Results and Discussion: Metal concentrations in the fruits decreased in the order (mg/kg): Zn (7.155) > Cu (3.376) > Pb (0.558) > Cr (0.447) > Cd (0.196). Estimated daily intake indicated increasing exposure in the sequence Cu < Zn < Cr < Cd < Pb for both adults and children. Hazard Quotients for Cd and Cu exceeded 1 and Hazard Index values (7.2903–

7.6973) were above the acceptable limit, indicating notable non-carcinogenic risks. Carcinogenic risk assessment showed Cr levels (1×10^{-3} to 1.2×10^{-3}) and Cd levels (3.8×10^{-4} to 4.2×10^{-4}) above permissible thresholds, while Pb (2.6×10^{-5} to 2.8×10^{-5}) remained within acceptable limits.

Conclusion: Overall, the findings reveal significant health risks from heavy metal exposure through papaya consumption and emphasize the need for ongoing environmental monitoring, particularly for chromium due to its elevated carcinogenic potential.

Novelty: This study will provide the first evidence of heavy-metal contamination and associated human health risks from *Carica papaya* irrigated with abattoir wastewater, highlighting a previously unexamined pathway of exposure within the local food chain. Future studies could extend this work by studying other food materials in the country.

Keywords: carcinogenic risk, daily intake, hazardous index, hazard quotient, transfer factor

Introduction

Food safety remains a critical global public health issue, with dietary intake recognized as the primary pathway for human exposure to environmental contaminants. Studies indicate that more than 90% of such exposure occurs through food consumption, compared to relatively minor contributions from inhalation and dermal contact (Zahir *et al,* 2025). It is estimated that approximately 30% of human cancers are linked to chronic, low-level exposure to carcinogenic substances present in the diet (Abnet, 2007). These contaminants include certain microminerals when present at concentrations above physiological requirements as well as toxic heavy metals.

Heavy metal contamination is increasingly recognized as a major environmental and public health challenge, largely due to the persistence, toxicity, and non-biodegradable nature of these elements (Aweng *et al,* 2011). Unlike organic pollutants, heavy metals accumulate in soils, water, and biota, with the potential to bio-magnify along the food chain, thereby threatening human health, animals, and entire ecosystems (Briffa *et al,* 2020). Commonly reported heavy metals in polluted environments include chromium (Cr), copper (Cu), lead (Pb), cadmium (Cd), and zinc (Zn). While Cu and Zn are essential micronutrients required in trace amounts for normal biological functions, their excessive buildup can lead to toxicity. In contrast, Pb, Cd, and certain valence states of Cr have no biological role and are highly toxic even at minimal concentrations (Navarrete & Asio, 2011).

Various sources of pollution have been identified, which may originate from point sources such as industries, refineries, and mining activities, or from non-point sources like cars, buses, and trains. Abattoirs have also been recognized as contributors of many pollutants (Oluwole *et al,* 2021). Among these contaminants, heavy metals are frequently present in trace amounts. Even at low concentrations, these metals pose significant environmental risks, as they can accumulate in living organisms through bioaccumulation or bio-concentration (Wong *et al,* 2002). Additionally, abattoirs generate substantial amounts of secondary waste, primarily in the form of large quantities of animal feces (Seaward, 2004).

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Abattoirs are facilities where animals are slaughtered and processed for human consumption, resulting in the generation of large amounts of waste. These wastes contain various pollutants that can inhibit the growth of soil microorganisms, plants and animals, thereby impacting the entire ecosystem. A significant portion of abattoir waste consists of heavy metals (Osu and Okereke, 2015). Abattoirs are recognized as potential sources of environmental contamination due to the large volumes of wastewater, blood, fats, and other organic wastes they discharge into the surrounding environment (Mozhiarasi and Natarajan, 2022). These effluents may contain significant amounts of heavy metals originating from animal feed, veterinary drugs, disinfectants, and equipment used in meat processing (Nandomah and Tetteh, 2023). When improperly managed, such wastes infiltrate surrounding soils, surface water, and groundwater, eventually entering the food chain through crops cultivated in contaminated soils or irrigated with polluted wastewater (Mohammed *et al,* 2020).

Carica papaya (*C. papaya*) is one of the most widely consumed tropical fruits, valued for its nutritional and medicinal benefits. Its cultivation in peri-urban and rural areas often occurs near residential and commercial zones, including abattoirs (Bhattacharjee, 2001). Due to its fast growth and high-water content, papaya can readily absorb contaminants from soil and irrigation sources, making it a potential bio-indicator of environmental pollution (Christen *et al,* 2008). Assessing heavy metal accumulation in papaya fruits is therefore critical for evaluating the extent of contamination and potential risks to human health.

Ikwiriri Ward located in Rufiji District, Tanzania, hosts an active abattoir that generates substantial waste on a daily basis. The proximity of this abattoir to cultivated lands raises concerns about the possible transfer of heavy metals into soils, wastewater, and edible crops such as papaya. However, little is known about the extent of heavy metal contamination in this area.

Objectives of the study

This study therefore aims to assess the levels of selected heavy metals (Cr, Cu, Pb, Cd, and Zn) in *Carica papaya* fruits and soils around the abattoir in Ikwiriri Ward. This study was quidded by the following specific objectives:

i. To analyze the levels of heavy metals in soils where *Carica papaya* grown and irrigated with abattoir wastewater.
ii. To determine the concentration of heavy metals in the edible parts of *Carica papaya* grown on wastewater-irrigated farms.
iii. To evaluate potential non-carcinogenic and carcinogenic health risks associated with heavy metal exposure using established risk assessment models.

Literature Review

Abattoir waste has been used as manure or irrigation purpose for the crop, vegetables and fruits production. These waste materials consist of several pollutants such as faeces, blood, bone, hone, fat, animal trimmings, paunch content and urine from operations, stunning or bleeding, carcass processing, and by-product processing (Thomas et al., 2024). Abattoir wastewater constitutes one of the greatest threats to environmental safety probably because of

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the presence of mineral constituents. Among the numerous contaminants present in abattoir wastewater, heavy metals are of particular concern because of their persistence in the environment, ability to bioaccumulate, and toxic effects on living organisms (Abidola, et al., 2025). In abattoir settings, these metals may be introduced into wastewater through contaminated animal feed, the use of veterinary pharmaceuticals, and different stages of the slaughtering and processing operations. These elements are of particular concern because they can accumulate in soil and crops, enter the human food chain, and pose significant human health risks upon consumption (Savari et al., 2025).

The prolonged exposure of crop plants in soils with heavy metals increases their absorption and depends on factors such as cation exchange capacity, clay content, pH, organic matter content, and redox potential; these determine the soil capacity to retain or mobilize heavy metals (Amaro-Espejo et al., 2020). The solubility of trace cations increases as the pH is more acidic, thus increasing its mobility in soil and availability of absorption to crop plants; it has been reported that at pH 5, it is considered a medium absorption for Cd, weak for Co and Zn, and too weak for Cu, Cr, and Pb (Barrow and Hartemink, 2023).

There have been a number of studies on heavy metals in soils and carica papaya, including an assessment of heavy metal contents in roadside dust, wastewater-irrigated papaya, showing carica papaya can bioaccumulate heavy metals in fruit and leaves when grown in contaminated environments. Assessment of heavy metal concentrations in pawpaw (Carica papaya Linn.) around automobile workshops (Eludoyin and Ogbe, 2017) and the assessment of heavy metals in pawpaw (Carica Papaya) cultivated near a dumpsite, exposed to environmental pollution and susceptible to possible absorption of those metals (Ikenna et al., 2025). Hence recommended that farming activities proximate to waste dumps are to be checked by remediating the soil prior to planting and sensitizing the farmer on the effect of waste dump activities on the soil and plants**.** Given *Carica papaya's* potential to bioaccumulate metals, consumption of papaya irrigated with such wastewater could expose local communities to chronic health problems, including kidney damage, neurological disorders, and increased cancer risk. Risk assessment helps identify potential exposure levels and protect consumers' health.

However, none of these studies have investigated the influence of abattoir wastes on C. papaya, despite the fact that it is a common plant growing naturally around abattoir house in most of African countries including Tanzania. This study aims to assess human health risks associated with heavy metals contamination in *carica papaya* irrigated with abattoir wastewater in Ikwiriri Ward. While direct research for Ikwiriri Ward is lacking, regional evidence from Tanzania and global trends supports the plausibility of heavy metal accumulation in crops irrigated with untreated or poorly treated abattoir wastewater.

Materials and Methods

Study Area

This study was taken at Ikwiriri Ward, Rufiji District of Pwani Region, situated at latitude -7.956º and longitude 38.972º. The area is bordered to the north by Kisarawe and Mkuranga

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Districts, to the east by the Indian Ocean, to the south by Kilwa District in Lindi Region, and to the west by Morogoro Region.

Sample Collection

Before sample collection, a reconnaissance survey was conducted to identify the study areas. Fruit and soil samples were collected in January - February 2025. Five (5) partially ripe Carica papaya (*C. papaya*) fruits were harvested from selected trees near the abattoirs. The harvested fruits were bagged, properly labeled, and transported to the laboratory for heavy metal analysis following standard procedures.

Five soil samples (about 500 g each) from garden where *C. papaya* fruits grown were collected at a depth of about 15 cm using a hand auger, stored in in pre-cleaned polyethylene bags and sent to GST Tanzania laboratory where it is oven-dried at 60°C for two days. At the discharge point of the abattoirs, the sample bottles (polyethylene bottles) were properly labeled and rinsed twice with the wastewater before collection. Information such as the date of collection, location and serial identification for each sample was recorded on labels affixed to each container. A total of three samples of wastewater (effluent) were collected to three pre-cleaned bottles and acidified with 1 ml HNO_3. The purpose of the acid is to keep the metals in solution and to avoid adsorption to the container walls.

Sample preparation and digestion

The carica papaya fruit samples were washed thoroughly under running tap water and peeled. The edible part was crushed using a domestic blender and filtered using a sieve. About 2g of the sample juice was weighed out on a weighing balance and put in a beaker and 10mL of a mixture of nitric acid and perchloric acid in the ratio (4:1). The mixture was then digested for 15 minutes, allowed to cool, and diluted with distilled water. The mixture was filtered through acid-washed Whatman No. 44 filter paper into a 50 mL volumetric flask and diluted to the mark volume. The sample solution was then aspirated into the Atomic Absorption Spectroscopic machine at intervals.

The soil samples were grounded with a mortar and pestle and sieved through a 2 mm sieve. Approximately 1.0 g of the oven-dried, ground sample was weighed into a 250 mL beaker that had been previously washed with nitric acid and distilled water. A mixture of 5 mL HNO_3, 15 mL concentrated H_2SO_4, and 0.3 mL $HClO_4$ was added to the sample using a pipette. The mixture was digested in a fume cupboard, with heating continued until a dense white fume appeared. This was then digested for 15 minutes, allowed to cool, and diluted with distilled water. The mixture was filtered through acid-washed Whatman No. 44 filter paper into a 50 mL volumetric flask and diluted to the mark volume. The sample solution was then aspirated into the Atomic Absorption Spectroscopic machine at intervals.

To determine the metal concentration in wastewater from abattoir, the first step is to concentrate the metal, minimizing any potential interference. The wastewater samples from each sampling bottle were thoroughly mixed by shaking. A 50 mL filtered aliquot of each wastewater sample was pipette into a digestion flask. The metal content in the water was determined by digesting the sample in 3 ml of concentrated HNO_3 and 3 mL of H_2O_2 at temperatures below 80°C for 1 hour until a clear solution was obtained. This clear solution

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was then diluted to 100 ml with distilled water in a volumetric flask, and a blank digestion was performed in the same manner (Birtukan and Gebregziabher, 2014). The blank solution contained all reagents except the wastewater. All samples were digested in triplicate. The digests were analyzed for toxic heavy metals using Atomic Absorption Spectroscopy (AAS) equipped with a continuous flow of Vapour Generation Accessory (VGA) at Geological Survey of Tanzania (GST).

Quality Assurance

Calibration of the instrument was done by using standard values to ensure quality control. Quality control was ensured through the use of standard laboratory measurements and quality control methods, including replication, the use of standards for each metal investigated, and verification of instrument accuracy. Standard solutions for lead (Pb), copper (Cu), iron (Fe), zinc (Zn), and arsenic (As) were supplied by Merck (Germany) with a purity level of 99.98%. A 1000 mg/L standard solution for Pb, Cu, Zn, Fe, Cr and Cd was prepared, and an average standard concentration of 100 mg/L was obtained. Subsequently, working standards of 0.001, 0.015, 0.15, 1.05, and 2.50 mg/L were prepared using 1% HNO_3. The detection limits ranged from 0.001 to 0.0015 mg/L. In this way, deionized water was used throughout the work. The average range recoveries for soil, wastewater and fruit were Pb (98 -103%), Cu (93 - 96%), Cd (90 - 98%), Cr (94 - 97%) and Zn (91 - 95%).

Human Health Risk Assessment

Soil to Fruit Transfer Coefficients

Soil-to-fruit transfer is a major pathway for human exposure to metals through the food chain. The Transfer Factor (TF) is a parameter used to describe the movement of trace elements from soil to fruit and it is influenced by both soil and plant properties (Opaluwa, *et al,* 2012). The percentage transfer coefficient is calculated by dividing the concentration of heavy metals in vegetables by the total heavy metal concentration in the soil (Equation 1).

$$TF = \frac{Conc_{fruits}}{Conc_{Soil}} \text{ x } 100 \qquad (1)$$

This coefficient quantifies the relative differences in metal bioavailability to plants and depends on the properties of both soil and plants. A higher transfer coefficient indicates either poor retention of metals in soils or a greater efficiency of plants in absorbing metals, while a low coefficient suggests strong sorption of metals to soil colloids (Wilson and Pyatt, 2007).

Risks of individual heavy metals

Risk assessment is defined as the methods of evaluating the probability of occurrence of any given probable amount of the harmful health impacts over a determined time period (Wongsasuluk, et al, 2014). The health risk assessment of each contaminant is normally based on the estimation of the risk level and is classified as carcinogenic or non-carcinogenic health hazards (Custodio, *et al,* 2020). To estimate the heavy metal contamination and potential carcinogenic and non-cancer health risk caused via ingestion of heavy metals in *C. papaya* fruits; Hazard Quotients (HQ) and Hazard Index (HI) to adults were used.

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Estimated Daily Intake of Heavy Metals

The estimated daily intake (EDIM) of heavy metals was calculated based on the equation (1):

$$EDIM = \frac{C_{HM} * C_f * D_{fi}}{Av_{BW}} \quad (1)$$

Where C_{HM}, C_f, D_{fi} and Av_{BW} denote the concentration of heavy metals, conversion factor, daily food intake and average body weight respectively. A conversion factor of 0.085 was applied to convert the fresh sample weight to dry weight (Avila et al, 2017). Calculations were conducted based on the standard assumptions used in the integrated USEPA risk analysis (USEPA, 2005), considering adults and children with average body weights of 60 kg and 32.7 kg, respectively. The average daily consumption rates for fruits were assumed to be 0.345 kg $person^{-1}$ day^{-1} for adults and 0.173 kg $person^{-1}$ day^{-1} for children (Nie et al, 2023).

Non-Carcinogenic Risk Assessment

Hazard Quotient (HQ)

For the non-carcinogenic risk this was evaluated using the hazard quotient (HQ), which was calculated by dividing the exposure value by the reference dose (Equation 2) (Custodio, et al, 2020).

$$HQ = \frac{EDIM}{RfD} \quad (2)$$

Where HQ is the hazard quotient for ingestion or skin contact, EDIM is estimated daily intake. According to Nkpaa, et al, (2016), the RfD (mg/kg.day) standard values for ingestion are Cr = 0.003, Cd = 0.001, Pb= 0.0035, Zn = 0.3 and Cu = 0.004. If a value of HQ ≤ 1 indicates that adverse health effects are unlikely. When HQ > 1 reveals probable adverse health effects, while when HQ > 10 indicates high chronic risk. The general potential for non-carcinogenic effects has been assessed by integrating the HQs calculated for each element and expressed as a hazard index.

$$HI = \sum_{i=1}^{n} HQ = HQ_{Pb} + HQ_{Cd} + HQ_{Zn} + HQ_{Cu} + HQ_{Cr} \quad (3)$$

Where HI is the hazard index for ingestion or dermal contact, n is the total number of chemical elements considered. If HI < 1, the non-carcinogenic adverse effect due to a particular route of exposure or chemical is assumed to be insignificant.

Carcinogenic risk and ingestion cancer slope factors

According to ATSDR (2010) and Ma'aruf *et al,* (2024) ingestion cancer slope factors are used to evaluate the lifetime (average of 70 years) probability of contracting cancer due to certain levels of exposure to a potential carcinogen. The carcinogenic risk is expressed as:

$$C_R = EDIM \text{ x } C_{SF} \quad (4)$$

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Where C_R, EDIM and C_{SF} are the carcinogenic risk, estimated daily intake of heavy metals and ingestion cancer slope factor respectively. According to Yang *et al,* (2015), the C_{SF} of assessed metals (mg/kg.day) were Cr (0.5), Pb (0.0085), and Cd (0.38). The classification of carcinogenic risk index between 10^{-6} and 10^{-4} indicates an interval of allowable predicted lifetime risks for cancer causing agents. Thus, chemicals having risk factors less than 10^{-6} may not be treated as chemicals for further concern (Nkpaa 2016).

Results and Discussion

Concentration of Heavy Metals in Soil around Abattoir

The concentration of heavy metals in soil within an abattoir can be affected by secondary wastes generated during the slaughtering process. These secondary wastes include blood, fat, organic and inorganic contents from the animal stomach and various chemicals used during processing (Oluwole *et al,* 2021). The distribution of mean concentrations of elements present in the soils is shown in Table 1. In order to reduce the levels of heavy metals contamination in agricultural soils, the National environmental policies should be reinforced. According to Tanzania Environmental Management (Soil Quality Standards) Regulation (TBS, 2007), the maximum allowable limits in soil should not exceed should not exceed these levels (mg/kg); Cd (1.0), Cr (100), Pb (200), Cu (200) and Zn (150).

Table 1 Concentration of Selected Heavy Metals in Soil around Abattoir House

Soil (n = 5)	Cr	Cu	Pb	Zn	Cd
Maximum	34.466	15.672	1.793	103.254	1.739
Minimum	29.563	13.996	0.645	94.204	0.947
Mean	31.591	14.778	1.043	97.782	1.327
STD	1.849	0.676	0.458	3.645	0.356
CV (%)	5.853	4.574	43.744	3.728	26.827

Levels of Cr varied between 29.563mg/kg and 34.466 mg/kg with a mean value of 31.591±1.849 mg/kg. This range is higher than 4.25 to 5.86 mg/kg reported by Ubwa *et al,* (2013) ranged from 0.072 to 0.136 mg/kg. The distribution of Cr in studied abattoir soils indicated very low degree of variability as shown by the coefficient of variation (CV) value of 5.853%. This means chromium levels in soil near the slaughterhouse are relatively consistent from site to site (De-Silva *et al,* 2023). Therefore, chromium contamination source (e.g., abattoir waste or runoff) is evenly distributed and the soils have similar characteristics (such as pH, texture, or organic matter) that influence chromium retention.

Copper (Cu) is an essential micronutrient required for the proper growth and development of plants. However, excessive concentrations can lead to copper toxicity, a condition that disrupts biological systems when Cu levels exceed the optimal range (Vlcek and Pohanka, 2018). The availability of Cu in soil is influenced by several factors, particularly soil pH its solubility tends to be higher in acidic soils compared to alkaline ones as well as the presence of organic matter (Keiblinger *et al,* 2018). In this study, Cu concentrations ranged from 13.996 to 15.672 mg/kg, with a mean value of 14.778 ± 0.676 mg/kg. These findings are

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consistent with previous research on Nigerian abattoir soils by Etuk *et al,* (2019), who reported values ranging from 14.74 to 23.03 mg/kg with a mean of 18.88 ± 3.22 mg/kg. The observed range in this study is lower than the 36.46–40.60 mg/kg reported by Owagboriaye *et al,* (2016) but higher than the 0.10–0.20 mg/kg obtained by Sanda et al, (2016) in similar environments. The distribution of Cu in studied abattoir soils indicated very low degree of variability as shown by the coefficient of variation (CV) value of 4.574 %.

Levels of Pb obtained in studied abattoir soils varied from 0.645 mg/kg to 1.793 mg/kg with a mean value of 1.043±0.458 mg/kg. This range is lower than 0.185 – 1.676 mg/kg and 0.001 – 2.900mg/kg reported by Ubwa *et al.* (2013) and Osu & Okereke (2015) respectively. The distribution of Pb in the studied abattoir soils indicated a fair degree of variability with a CV value of 43.744%. This indicates anthropogenic addition of Pb by abattoir wastes to the studied soils. However, the range obtained is lower than 200 mg/kg recommended for agricultural soil in Tanzania (TBS, 2007). Consequently, Pb may not be considered a pollutant in the studied soils but its availability should be observed to avoid bioaccumulation over time with associated problems on the environment.

Zinc (Zn) levels in studied abattoir soils ranges from 94.204 – 103.254 mg/kg with mean 97.782 ± 3.645 mg/kg. This range is higher than 18.70 – 21.60 mg/kg and 1.1302 – 5.2362 mg/kg reported by Neboh et al. (2013) and Ubwa *et al,* (2013) respectively in abattoir waste-impacted soils. Variation in the distribution of Zn between the studied abattoirs soils was low as indicated by a CV value of 3.728%. This could be attributed to the high availability of Zn in the study area (Onyedika, 2015). However, the obtained mean value is lower than 150.00 mg/kg maximum limit for agricultural soil in Tanzania (TBS, 2007). Hence, the level of Zn at each studied abattoir soil could be essential for normal enzymatic activities in plants.

Levels of Cd in studied abattoir soils ranged from 0.947 – 1.739 mg/kg with a mean value of 1.327 ± 0.356 mg/kg. This range is in line with previous study (Etuk *et al,* 2019), in abattoir soils ranged from 1.08 – 1.52 mg/kg with a mean value of 1.30±0.16 mg/kg. higher than 0.006 – 0.014mg/kg and 0.43 – 0.74mg/kg reported by Sanda *et al,* (2016) and 0.001 – 0.007mg/kg reported by Simeon and Friday (2017) respectively in abattoir waste impacted soils. The distribution of Cd in the studied abattoir soils indicated a fair degree of variability with a CV value of 26.827 %. This indicates anthropogenic addition of Cd by abattoir wastes to the studied soils. Accordingly, activities in these abattoirs may have introduced additional Cd into soils studied. The mean value is also higher than 1.0 mg/kg recommended Tanzania agricultural soil (TBS, 2007). Thus, considering its toxic nature, the level our environment should be closely monitored to forestall health problems associated with Cd toxicity along the food chain.

Heavy Metal Concentration in Carica Papaya Fruits

Plants have an inherent ability to absorb toxic substances, including heavy metals, which can subsequently be transferred along the food chain (Mohamed, *et al,* 2025). Therefore, heavy metal contamination in plants is a matter of serious concern, as plant-based foods constitute a significant part of the human diet. The results presented in Table 2 show the concentrations of the analyzed heavy metals.

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Table 2 Heavy Metal Concentrations in Carica papaya (Carica Papaya) Friuts (mg/kg)

Carica papaya (n = 5)	Cr	Cu	Pb	Zn	Cd
Maximum	0.518	4.808	0.956	7.842	0.312
Minimum	0.398	2.796	0.209	6.931	0.097
Mean	0.447	3.376	0.578	7.155	0.196
STD	0.047	0.819	0.278	0.857	0.078
WHO/FAO (2012)	0.1	2.0	0.2	99.4	0.02

The concentrations of heavy metals in *C. papaya* followed the decreasing order: Zn > Cu > Cr > Pb > Cd. Zinc (Zn) is an essential trace element and a vital component of numerous enzymes involved in metabolic processes. However, acute oral exposure to excessive amounts of Zn may cause symptoms such as nausea, vomiting, tachycardia, vascular shock, and pancreatic dysfunction. In this study, *C. papaya* fruits exhibited the highest mean concentration of Zn (7.155 ± 0.857 mg/kg). This value is comparable to the 7.31 mg/kg reported by Ihesinachi and Eresiya (2014) in Nigeria. Furthermore, the Zn concentration obtained in this study is approximately ten times lower than the maximum permissible limit of 99.40 mg/kg established by WHO/FAO (2012), indicating that the Zn levels in the analyzed samples are within safe limits.

Copper (Cu) is an essential trace element necessary for maintaining good health when present within appropriate limits. However, excessive accumulation of Cu in fruits can be detrimental to human health, while insufficient intake may lead to various physiological disorders such as growth retardation, skin lesions, and gastrointestinal disturbances. In the present study, the concentration of Cu in *Carica papaya* fruits ranged from 2.796 to 4.808 mg/kg, with a mean value of 3.376 ± 0.819 mg/kg. This maximum concentration falls within the WHO/FAO (2012) permissible limit of 0.5 mg/kg.

Lead content of the *C. papaya* ranged from 0.209–0.956 mg/kg with mean 0.578 ± 0.278 mg/kg. Lead is non-essential and toxic even at low concentrations. The WHO/FAO (2012) safe limit for Pb in fruits is 0.01 mg/kg. The mean exceeds the maximum acceptable suggesting possible environmental contamination likely from vehicle emissions, industrial waste, or contaminated irrigation water.

The level of Cr ranged from 0.398 – 0.518 mg/kg with mean 0.447 ± 0.047 mg/kg. Most importantly, Cr level observed is 4 times higher than WHO/FAO (2012) permissible limit of 0.1 mg/kg. This finding was however is contrast to that of Sobukola *et al,* (2010) and Ogunkunle *et al,* (2014) who reported the absence of chromium in some fruits from selected markets in Nigeria.

Cadmium (Cd) is a non-essential and highly toxic heavy metal commonly found in foods and natural waters, with a tendency to accumulate primarily in the kidneys and liver (Khan et al,2022). The concentration of Cd in fruits varies depending on the plant species and its ability to absorb cadmium from the surrounding environment where it is cultivated (Mausi *et*

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al, 2014). In the analyzed *C. papaya* samples, Cd concentrations ranged from 0.097 to 0.312 mg/kg, with a mean value of 0.196 ± 0.078 mg/kg.

Transfer Coefficient

The soil-fruit transfer coefficient is a crucial factor in human exposure to heavy metals via the food chain, as it describes the movement of contaminants from soil to plants. In respective to this, we have evaluated the transferability of heavy metals from soil to fruit this study considered *Carica papaya*, which is commonly consumed in study area and data for percentage bioconcentration factor (BFC) of the heavy metals analyzed has been given in Figure 1.

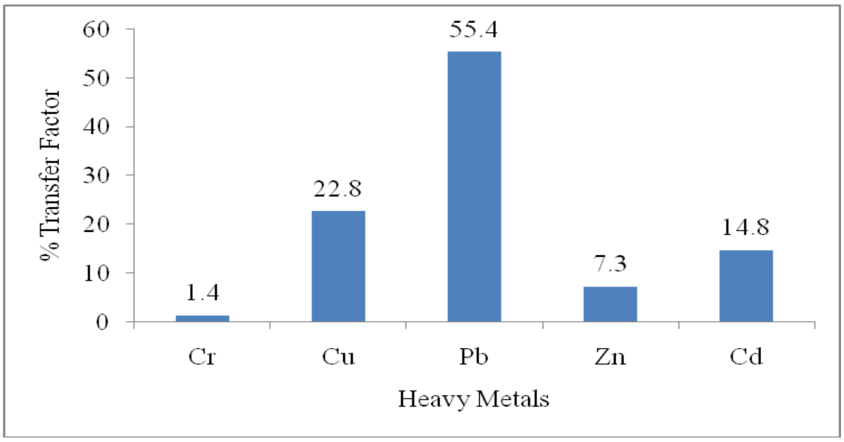

Figure 1: The Percentage Transfer Coefficient

The percentage transfer coefficients for heavy metals in descending order are Pb > Cu > Cd > Zn > Cr. These findings indicate that Pb has the highest transferability showing the greatest absorption capability. Additionally, the transfer coefficient is influenced by the bioavailability of the metal, the levels of metal in the soil, the chemical form of the metal, plant uptake capabilities, and the growth rate of the plant species (Tinker, 1981).

The elevated concentrations of these heavy metals could be due to increased contamination from wastewater irrigation from abattoirs, solid waste disposal, sludge applications, solid waste combustion and agrochemicals (Enock et al., 2025). Physical and chemical parameters such as organic matter content, pH, cation exchange capacity, soil texture, and clay content (Mustafa *et al,* 2024) can influence the migration and transformation of metal ions. Plants play a crucial role in the biotransformation of chemical elements from soil, air, and water, making soil metal content a significant entry point into the food chain. The physical and chemical state of the metal is critical for its transport mechanisms and bioaccumulation (Hong, et al, 2023). These findings could also explain why Cr was detected in the soil was very low compared to levels in the fruits. Indeed, metals are more not readily soluble in water forming ionic forms, which can be up taken by plants (Castañeda, *et al,* 2025).

Estimated dietary intake of heavy metals

Assessment of dietary intake of food is an essential tool for measuring the amount heavy metal intake which may be lead to deficiencies or health risks. The average concentration of heavy metals in fruit dietary intake of metals for adult individual and children was estimated

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and presented in Table 3. According to FAO/WHO (2025) the Maximum Tolerable Dietary Intake (MTDI) mg/day of heavy metals of interest are Cr = 0.008, Cu = 30, Pb = 0.0005, Zn = 0.43 and Cd = 0.002.

Table 3: Heavy Metals in Carica papaya Fruit Daily Intake for Adult and Children (mg/kg.day)

Heavy Metal		Cr	Cu	Pb	Zn	Cd
Estimated Daily Intake (EDIM)	Adult	0.0020	0.0194	0.0033	0.0413	0.0011
	Child	0.0024	0.0179	0.0031	0.0380	0.0010
% Contribution to MTDI	Adult	32.1	0	666	9.6	56.5
	Child	29.5	0	612	8.8	52.0
Hazard Quotient (HQ)	Adult	0.6667	4.850	0.9429	0.1377	1.100
	Child	0.8000	4.475	0.8886	0.1267	1.000
Carcinogenic Risk (C_R)	Adult	0.0010	-	0.000028	-	0.00042
	Child	0.0012	-	0.000026	-	0.00038

Based on average values the daily intake of Pb is higher than Maximum Tolerable Dietary Intake (MTDI) mg/day (FAO/WHO, 2025). This indicates Pb is significantly contributing to possible health risks from fruit consumption. Based on average % contribution, the result showed that daily intake of metals through *C. papaya* fruit consumption in Ikwiriri abattoirs was in the ascending order Cu < Zn < Cr < Cd < Pb for both adults and children. This showed that the EDIM for known carcinogen elements (Cr, Cd and Pb) were higher than essential trace metals like Cu and Zn.

The value obtained is lower than values detected earlier (Elbagermi, *et al*, 2012), where the estimated daily intake of heavy metals from fruits were Pb (0.0248), Cd (0.0133), Zn (0.008) and Cu (0.0497).

Hazard Quotient (HQ)

In order to give an estimate of the non-carcinogenic health risk due to oral exposure to heavy metals, the hazard quotient (HQ) and hazardous indexes (HI) of heavy metal in carica papaya fruit was calculated (Table 4). The HQ in ascending order was Zn < Cr < Pb < Cd < Cu for both adults and children (quantitative terms), where Cd and Cu were > 1, indicating that the residents at the sampling site may be exposed to potential non-carcinogenic health risk due to Cd and Cu intoxication. Thus, other heavy metals (Zn, Cr and Pb) were less than one which implies that the daily intake of these metals by the populace were below the reference oral dose and the population is may be safe from Zn, Cr and Pb intoxication. Getacho *et al.* (2025) reported that maximum HQ value poses relatively higher potential health risk to human beings especially for residents in the locals with serious metal contamination. Thus, the daily intake of Cu and Cd for most of the carica papaya samples from Ikwiriri abattoirs were above the reference oral dose indicating a level of concern.

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Hazardous Indexes (HI)

The Hazard Index (HI) values for the heavy metals analyzed ranged from 7.2903 to 7.6973, exceeding the threshold value of 1, which indicates a non-acceptable level of non-carcinogenic adverse health effects. Therefore, the HI recorded in the Ikwiriri slaughterhouse suggests that heavy metal contamination may contribute to cumulative health risks through the consumption of *C. papaya* fruit. The elevated HI values for all the heavy metals studied highlight a significant potential health risk to consumers. This suggest that the use of untreated abattoir wastewater is unsafe, as it leads to heavy metal accumulation in edible crops at levels that can harm consumers.

Similarly, a study by Ametepey *et al,* (2018) reported HI values ranging from 6.51 to 29.30. The consequences of such contamination could be more severe for vulnerable populations within the slaughterhouse environment, particularly the elderly and pregnant women, due to potential health risks associated with heavy metal accumulation through *C. papaya* consumption. Although fruit intake represents only a portion of total dietary consumption, other complementary foods such as vegetables and fish (Wang *et al,* 2005; Saria, 2017), meat (Zheng *et al,* 2007; Bortey-Sam *et al,* 2015), and rice (Zheng *et al,* 2007) may also contribute to, or further increase, heavy metal exposure.

Carcinogenic Risk (CR)

Cancer slope factors were applied to estimate the carcinogenic risk (CR), and the results are presented in Table 4. The estimated average lifetime cancer risk due to the intake of heavy metals (Cr, Pb, and Cd) ranged from 2.8×10^{-5} to 1.0×10^{-3} for adults and 2.6×10^{-5} to 1.2×10^{-3} for children. According to the USEPA (1989) guidelines, except for Pb, the CR values for Cr and Cd fall within the acceptable range of predicted lifetime cancer risk. Therefore, over a lifetime exposure period of 70 years, these values represent the probability of developing cancer as prescribed by USEPA standards. The average carcinogenic risk values obtained for Cr and Cd in this study suggest that these metals should be considered for further evaluation as chemicals of concern (Aendo *et al,* 2022). At the time of this study, data on the carcinogenicity or mutagenicity of Zn and Cu in humans and animals remained limited or inconclusive (Assem *et al,* 2011).

Conclusion and Recommendations

This study demonstrated that *C. papaya* cultivated around the Ikwiriri abattoir accumulates significant levels of heavy metals originating from contaminated soils influenced by abattoir waste discharge. Zinc and chromium were the predominant metals in soil, while zinc and copper were most abundant in *C. papaya* fruits. Transfer coefficient analysis indicated that lead exhibited the highest mobility and bioaccumulation potential. Health risk assessments revealed that daily intake of certain metals particularly cadmium and lead may pose health hazards to both adults and children. Furthermore, Hazard Quotient values for cadmium and copper exceeded recommended safety limits, and the elevated Hazard Index values confirmed substantial non-carcinogenic risks.

Carcinogenic risk analysis showed that chromium and cadmium concentrations exceeded acceptable thresholds, suggesting increased lifetime cancer risk, whereas lead remained within permissible levels. Overall, the findings provide strong evidence that consumption of *C. papaya* grown near the Ikwiriri abattoir presents both carcinogenic and non-carcinogenic health risks, reinforcing the need for improved environmental oversight and continuous monitoring of heavy metal contamination in the area.

Routine monitoring of heavy metals in soils, *C. papaya*, and other edible crops around the Ikwiriri abattoir is essential, with particular attention to chromium and cadmium due to their elevated risk profiles. The abattoir should adopt safer and more efficient waste handling and disposal practices to minimize environmental contamination. Further investigations should assess heavy metal accumulation in other locally consumed plants and evaluate long-term ecological and human health implications.

To reduce human health risks associated with heavy metals in *Carica papaya* irrigated with abattoir wastewater, abattoirs should implement basic but effective wastewater treatment technologies such as screening and sedimentation tanks, stabilization ponds, constructed wetlands, and low-cost filtration systems using sand, activated carbon, or biochar to remove heavy metals before discharge. The abattoir wastewater treatment technologies**,** farmer and community education and structured monitoring by local authorities provides a practical and sustainable approach to reducing heavy metal exposure and protecting public health in Ikwiriri Ward.

Study Limitations and Future Scope

The use of only five samples (n = 5) for both soil and *Carica papaya* fruits represents a notable limitation of the study. This sample size was adopted primarily due to resource and logistical constraints, including limited funding, time, and laboratory analytical costs associated with heavy metal determination. In addition, the study area is relatively homogeneous in terms of land use, irrigation source (abattoir wastewater), soil type, and farming practices, which reduced variability and supported the use of a smaller, representative sample size for this preliminary investigation.

Furthermore, the study was designed as an exploratory or pilot assessment aimed at generating baseline data on heavy metal contamination and associated human health risks in papaya grown under abattoir wastewater irrigation in Ikwiriri Ward. As such, the findings provide an initial indication of potential risks rather than definitive conclusions for the entire area.

Nevertheless, it is acknowledged that a small sample size limits the statistical power**,** generalizability, and robustness of the results. Therefore, the findings should be interpreted with caution, and future studies should incorporate larger sample sizes and multiple sampling periods to better capture spatial and temporal variability and to strengthen risk assessment outcomes.

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Author Contributions
JS: Conceptualization, methodology, data collection and laboratory analysis, data analysis, and writing an original draft. LY: Conceptualization, supervision, data curation, writing an original draft.
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