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Human health risk assessment of heavy metals in beer brands from Tanzania market

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ABSTRACT

Heavy metal contamination in the environment, often resulting from industrial activities, mining, and improper waste disposal, leads to the accumulation of heavy metals in soil, water, air, drinks and food. Prolonged exposure to these metals can cause serious health issues in humans, including neurological damage, kidney failure, respiratory problems, and an increased risk of cancer. High levels of heavy metals in food are hazardous to human health. Heavy metals can find their way into beer at different stages, including through raw materials, the brewing process, equipment, bottling, and storage. This study examined the presence of Cu, Cd, Pb, Cr, Fe, and Zn in ten of the most consumed beer brands in Tanzania using an atomic absorption spectrometer (AAS). The results showed that the concentration of heavy metals in the beer samples increased in the order of Zn < Cu < Fe < Cr. Cd and Pb were not detected in any beer samples. Compared to WHO guidelines, the levels of Zn and Cu were below the limit, while Fe and Cr exceeded it. Estimated daily intake (CDI), hazard quotient (HQ), hazard index (HI), and incremental lifetime cancer risk (ILCR) were used to evaluate the potential human health risks. The EDI values of Fe and Zn were lower than the provisional maximum tolerable daily intake (PMTDI) set by the FAO/WHO. However, the mean EDI for Cr surpassed the recommended value, posing a potential risk for moderate and high beer consumers. The HQ and HI values for Zn and Fe were below 1, signifying no non-carcinogenic health concerns. In contrast, Cr had HQ and HI values greater than 1, indicating a notable non-carcinogenic health risk through beers consumption. ILCR due to Cr ranged from 0.029 to 0.695. These ILCR values for Cr in all beer samples are above range of $10^{-6}-10^{-4}$ recommended by USEPA, suggesting a potential carcinogenic risk linked to this toxic metal and, consequently, a possible cancer risk for beer consumers. Therefore, beer manufacturers should continuously work to minimize public health risks. Additionally, further research involving a larger variety of beer brands and the implementation of policy interventions is needed.

1. Introduction

Heavy metal pollution has emerged as a major global environmental concern, with industrialization, urbanization, and agricultural activities all contributing to harmful metals discharge into ecosystems [1]. Heavy metals can be categorized into essential and toxic. Essential heavy meals are those required by the human body for proper growth and development, a health immunity system, and overall well-being. Those heavy metals include Fe, Mn, Cu, and Zn. Also, they have to be taken at in optimal level while consuming excess, it might affect human health. Toxic heavy metals are those metals that are noted for their potential toxicity especially in the human body and environment, even at lower levels for example, Cd, Cr, Pb, As and Hg [2–5].

Heavy metals come from both natural and man-made sources. In nature, they are released through events like volcanic eruptions, the breakdown of rocks, and forest fires, which release these metals into the environment. However, human activities significantly contribute to heavy metals pollution through industrial processes, mining, metal smelting, fossil fuel combustion, improper waste disposal, and the use of pesticides and fertilizers in agriculture. Contamination from electronic waste and sewage also adds to the spread of heavy metals in soil, air, and water [6–9]. The health effects of heavy metals depend on the type one is exposed to, duration, and level of exposure. Lead exposure can impair cognitive development in children, cause neurological disorders, and lead to anemia. Mercury damages the nervous system, resulting in cognitive and motor dysfunctions. Cadmium primarily affects the

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kidneys and bones, leading to kidney damage, osteoporosis, and respiratory problems. Arsenic, a known carcinogen, is linked to cancers of the skin, bladder, and lungs. Chromium can cause respiratory problems, kidney and liver damage, skin irritation, and has carcinogenic effects. Chronic exposure to these metals can also lead to immune, reproductive, and liver damage, making heavy metal contamination a significant public health concern [10,11].

Governments and researchers around the world are wrestling with the challenge of regulating and mitigating heavy metal pollution, which has long-term consequences for public health and the environment. Heavy metal contamination is typically exacerbated in poor countries, notably in Africa, by fast urbanization, insufficient environmental restrictions, and limited waste management infrastructure. Tanzania, one of East Africa's fastest-growing economies, has undergone rising industrial activity and urbanization, raising the risk of environmental degradation. Despite this, there has been little research on heavy metals contamination in Tanzania, notably on the effects on food and beverages used by the indigenous population. Screening food from heavy metals helps monitor environmental contamination. It provides data on pollution levels in soil, water, and air, which can help identify and mitigate sources of contamination [12,13]. Regular screening ensures that food products are safe, which helps maintain consumer confidence in food safety standards and the food industry. Regulatory bodies like the Food and Agriculture Organization (FAO), World Health Organization (WHO) and the Tanzania Bureau of Standards (TBS) have set maximum allowable levels of heavy metals in food products. Screening helps ensure that food products comply with these regulations, protecting consumers from exposure to harmful levels of heavy metals.

Beer is the most widely consumed alcoholic beverage in local and international regions and is the third popular drink after water and tea. Beer has been part of the human diet since at least 5000 BC [14]. It is usually made by fermenting cereals, which provide sugars and essential nutrients. Beer is mostly water, with carbs and alcohol that produce energy when metabolized by the body. Beer's alcohol contents normally range from 3.5 to 10 percentage weight/volume (% w/v) [14]. Moderate alcohol consumption is defined WHO as up to one 330 ml can of beer of about 5 % w/v) per day for women and up to two for men [14,15]. Heavy metals can enter beer at various stages, including raw materials, brewing processes, equipment, bottling, and storage [14,16]. The heavy metal contents in beer vary widely and are influenced by factors such as the type of raw materials, soil composition, agrochemical treatments (use of pesticides or fertilizers), and environmental pollution. Substances added during brewing, like hops, water, and flavoring agents, as well as the brewing and bottling equipment, can also introduce metal ions [17,18]. Recent studies have highlighted the persistent issue of heavy metal contamination in beer in various regions of the world such as Turkey [19], Nigeria [20], Ethiopia [21], India [22], Spain [23], Portugal [24], Brazil [25], Norway [26], Poland [27], Italy [28]. In Tanzania, many individuals, particularly those over 18, consume beer for various reasons, such as refreshment and enjoyment. However, there is no data on the heavy metal contents of beer consumed in Tanzania. This study aims to address this gap by providing a detailed assessment of health risks associated with heavy metals contamination in most commonly consumed beer brands in Tanzania. Therefore, this study determines the concentrations of Pb, Cd, Cr, Cu, Zn, and Fe in the ten (10) commonly consumed beer brands in Tanzania. The goal is to provide information on the average daily intake of these metals from beer consumption and assess associated potential human health risks.

2. Material and methods

2.1. Sample collection

Ten (10) samples of beers (S1-S10) from different brands were purchased in Iringa Municipal, Tanzania. All the collected beer brands were lager beers.The samples collected represent the most commonly frequently consumed beers. Beers were stored at a temperature below 12°C and not exposed to direct sunlight and transferred to Sokoine University of Agriculture (SUA).

2.2. Laboratory analysis and extraction of beer samples

The laboratory analysis was conducted at the SUA-Soil Science Laboratory, located within the Soil and Geological Sciences Department in Morogoro, utilizing an Atomic Absorption Spectrophotometer (Thermo Scientific iCE 3300 AAS)[29]. Only one sample per brand was tested. Metal analysis in the samples followed EPA 3052 guidelines, using wet digestion with a Microwave Digester for extraction. 1 ml of the sample was accurately pipetted into a clean, dry, and empty Teflon tube (digestion bottle)[29]. Other procedures for beer extraction are the same as reported in the previous study[29].

2.3. Quality control and assurance

The minimum detection limit (MDL) of the AAS was determined by running a blank solution, measuring the absorption three times with a 3-second integration period, and calculating the standard deviation (SD) from 10 consecutive readings. The AAS was calibrated using an external standard calibration method, and the response factor was applied to verify the linearity of the calibration. The correlation coefficient (r^2) was also calculated. Spiked sample analysis was conducted to assess the accuracy of the sample preparation process and to identify potential errors due to the preparation or matrix effects. A recovery study was performed to further evaluate the method's accuracy [29].

2.4. Heavy metals determination in beer samples

Working standard metal solutions were made from stock standard Pb, Cd, Cr, Cu, Zn, and Fe solutions. All measurements were carried out using a conventional air-acetylene flame. Pb, Cd, Cr, Cu, Zn, and Fe had lamp currents of 10, 12, 10, and 15 mA, respectively. Before beginning the analysis, the lamp current for each metal was set to 75 % and warmed for 30 minutes. Before analysis, the wavelengths for Pb, Cd, Cr, Cu, Zn, and Fe were 217, 228, 357, 324.8, 213.9, and 248.3 nm, respectively.

Standard working solutions of metals were prepared from stock solutions of Pb, Cd, Cr, Cu, Zn, and Fe. A standard air-acetylene flame was used for all measurements. The lamp for each metal was placed in the AAS, with the lamp current set to 10 mA for Pb, Cd, Cu, and Zn[29], 12 mA for Cr, and 15 mA for Fe. Each lamp was adjusted to 75 % of its capacity and warmed up for 30 minutes prior to the analysis. The Pb, Cd, Cr, Cu, Zn, and Fe wavelengths were set to 217 nm, 228 nm, 357 nm, 324.8 nm, 213.9 nm, and 248.3 nm, respectively. The analysis began with reading calibration standards, followed by blanks and samples. The quality of the analysis was controlled using blank and reference standards (TZS, 2003)[29]. Table 1 summarizes the heavy metals lamp currents, wavelength, (MDL)[29]. Other quality control and assurance procedures were the same as reported in previous study[29].

Table 1
Wavelength, lamp current and MDL of each heavy metal in the AAS analysis.

Element	Wavelength (nm)	Lamp current (A)	MDL (mg/kg)
Pb	217	10	0.013
Cd	228	10	0.0028
Cr	357	12	0.0054
Cu	324.8	10	0.0045
Zn	213.9	10	0.0033
Fe	248.3	15	0.0043

2.5. Human health risk assessment

In this study, human health risk assessment of heavy metals in beer involves assessing potential health effects of exposure to heavy metals (Cd, Cr, Pb, Zn, Fe and Cu). These metals can be found in beer due to environmental contamination, water, or brewing processes. Human health risk assessment of the levels of these metals in beer was done and then compared them to established safety limits. If the levels of heavy metals are above the safety limits, there may be a risk of adverse health effects for people who drink the beer. This assessment helps determine whether the levels of heavy metals in beer cause potential health risks of concern. In the following subsection, the non-carcinogenic and carcinogenic cancer risk methods are described. Non-carcinogenic substances are those that do not cause cancer and are determined by estimated daily intake (EDI) of metals, hazard quotient (HQ), and hazard index (HI). Carcinogenic substances are substances that can cause cancer. Incremental lifetime cancer risk (ILCR) can determine the carcinogenic risks.

2.5.1. Estimated daily intake (EDI)

The amount of metal ingested from beer can vary depending on the type of beer and the amount of drink. The estimated daily intake (EDI) of metals was calculated using Eq. 1[19,30].

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \tag{1}$$

The Estimated Daily Intake (EDI) is calculated in mg per kg of body weight per day (mg/kg/day). Here, C represents the metal concentration in the beer samples (mg/L), IR is the daily consumption rate of beer, assumed to be two beers per day for moderate consumers equal to 1 liter per day (500 ml per beer). EF stands for the exposure frequency, 365 days per year, and ED is the exposure duration, set at 52 years (from age 18–70). BW denotes body weight, taken as 70 kg, and AT represents the averaging time, calculated as the product of ED and EF (in days). After substituting the value of AT, Eq. 1 reduces to the equation.

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{IR}}{\mathrm{BW}} \tag{2}$$

2.5.2. Hazard quotient (HQ)

The hazard quotient (HQ) is a measure of the potential health risk associated with exposure to a particular substance. It is calculated using Eq. 3 [19].

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RFD}} \tag{3}$$

Where as, EDI is the estimated daily intake of metal(mg/kg/day), HQ is the hazard quotient and RFD is the reference oral dose in mg/kg/day.

2.5.3. Hazard index (HI)

HI is a number that represents the overall risk of exposure to multiple substances. It is calculated by taking the sum of the hazard quotients (HQ) for each heavy metal. Eq. 4 was used to determine the hazard index (HI)[19,31,32].

$$\mathrm{HI} = \sum HQ_{Pb} + HQ_{Cd} + HQ_{Cr} + HQ_{Cu} + HQ_{Zn} + HQ_{Fe} \tag{4}$$

2.5.4. Incremental lifetime cancer risk (ILCR)

Incremental lifetime cancer risk (ILCR) is an estimate of cancer risk from exposure to a substance through a specific exposure pathway. Eq. 5 was used to calculate ILCR by multiplying the EDI by the cancer slope factor (CSF) [33]. Table 2 represents the RfD and CSF of different heavy metals

$$\mathrm{ILCR} = \sum \mathrm{EDI} \times \mathrm{CSF} \tag{5}$$

Table 2
Reference oral dose (RfD) and cancer slope factor (CSF) for heavy metals[34].

Heavy metal	RfD (mg/kg/day)	CSF $(\mathrm{mg/kg/day})^{-1}$
Cu	4×10^{-2}	-
Cd	5×10^{-4}	6.3
Cr	3×10^{-3}	0.5
Pb	3.6×10^{-3}	0.0085
Zn	3×10^{-1}	-
Fe	7×10^{-1}	-

2.6. Statistical analysis

The data were analysed using Origin 2018 and IBM SPSS Statistics 26, which are statistical software programs for the social sciences. IBM SPSS was primarily used to check the correlation coefficients of heavy metals in beer samples, while Origin 2018 was utilized for plotting figures.

3. Results and discussion

3.1. Concentration of heavy metals in beer samples

Table 3 shows the concentration (mg/L) of heavy metals (Cu, Zn, Cd, Cr, Pb and Fe) in beer samples collected from Iringa municipal Tanzania. Table 4 compares heavy metals concentration with other studies from other countries in beer samples. Generally, the concentration of heavy metals in beer samples was in increasing order: Zn<Cu<Fe<Cr. Cd and Pb were not detected in any beer sample. The concentration of Cu obtained in this study ranged between 0.015 and 0.487 mg/L in samples S9 and S1, respectively. The mean Cu in the beer sample was 0.1903 mg/L. Cu was not detected in four samples of beer (S2–5, S7 and S8). The concentration of Cu in this study was below the permissible limit of 2 mg/L as set by WHO. The mean concentration of Cu is higher compared to a study reported in Turkey, Ethiopia, Norway (Table 4).

The concentration of Zn obtained in this study ranged between 0.011 and 0.363 mg/L in samples S10 and S1, respectively. The mean concentration of Zn in beer samples was 0.1495 mg/L, below the permissible limit of 5 mg/L as set by WHO. The mean concentration of Zn was lower compared to studies reported from Nigeria and Ethiopia, and higher compared to study conducted in Poland (Table 4). The heavy metals Concentration of Fe was between 0.172 and 2.587 mg/L in samples S2 and S1, respectively. The mean concentration of Fe in beer samples was 1.32 mg/L above the permissible limit of 1 mg/L set by WHO. The mean concentration of Fe was lower compared to studies conducted in Nigeria and Turkey and higher than in Norway (Table).

The concentration of Cr ranged between 4.055 and 97.214 mg/L in samples S10 and S9, respectively. The mean concentration of Cr in the beer sample was 66.5 mg/L above the permission limit of 0.05 mg/L set by WHO. The mean concentration of Cr obtained is higher than that reported by studies in Portugal (Table 4). The possible reason for the high chromium levels in beer is that the primary raw materials, such as malt and rice, contribute significantly to the chromium content in the production process. Also, the chromium content in beer rises considerably during the bottling process. It is assumed that this increase results from the transfer of chromium from materials like glass, caps, or steel used in the bottling machinery[37]. Additional, the amount of chromium in beer is influenced by the components used in the brewing process and by external sources, such as contamination from brewery equipment used to handle beer, such as filtration, carbonation, conditioning, fermentation, and packing material[24].

Humans need Cr(III), which is essential for fat, protein, and glucose metabolism. However, it has been observed that the Cr(VI) form poses a health risk to humans, primarily through acute and long-term inhalation exposures that exacerbate respiratory tract issues, the primary target

Table 3
Heavy metal concentrations (mg/L) of the analyzed beer samples.

Sample Name	Cu	Cr	Cd	Zn	Fe	Pb
S1	0.487	40.766	ND	0.363	2.587	ND
S2	ND	49.646	ND	0.190	0.172	ND
S3	ND	59.109	ND	0.209	1.267	ND
S4	ND	64.861	ND	0.076	0.781	ND
S5	ND	75.717	ND	0.207	0.870	ND
S6	0.165	85.916	ND	0.159	1.842	ND
S7	ND	91.788	ND	0.081	0.797	ND
S8	ND	95.907	ND	0.048	0.929	ND
S9	0.015	97.214	ND	0.151	2.481	ND
S10	0.094	4.055	ND	0.011	1.496	ND
Minimum	0.015	4.055	ND	0.011	0.172	ND
Maximum	0.487	97.214	ND	0.363	2.587	ND
Mean	0.190±0.179	66.498±27.951	ND	0.150±0.097	1.322±0.741	ND

ND=Not detected

Table 4
Comparison of concentration (mg/L) of heavy metals in beer samples with other studies.

Country	Heavy metals (mg/L)						Ref.
	Cu	Fe	Pb	Cr	Zn	Cd	
Turkey	0.086	9.925	0.000887	-	-	-	[19]
Nigeria	-	3.619	0.226	-	1.31	0.499	[20]
Ethiopia	0.0368	-	0.006	-	1.521	0.0014	[21]
India	-	-	-	-	-	0.0001	[22]
Spain	-	-	-	-	-	0.0002	[23]
Portugal	-	-	-	0.0033	-	-	[24]
Brazil	-	-	37	-	-	16	[25]
Norway	0.000032	0.000093	-	-	-	-	[26]
Poland	-	-	-	-	0.0026	-	[27]
Italy	-	-	0.00184	-	-	0.00016	[28]
Tanzania	0.190	1.322	ND	66.498	0.150	ND	Present study
WHO	2	1	0.2	0.005	5	0.05	[35,36]

ND=Not detected

organ for toxicity[38,39].

Table 5 shows the Pearson correlation coefficient of heavy metals in beer samples for one-tail ($p>0.05$). A modest positive correlation (0.47) was found between Fe and Zn, indicating a potential shared origin for these metals. A very weak negative correlation was observed between Cr and Zn (-0.067) also Cr and Fe (-0.029).

3.2. Non-carcinogenic and carcinogenic human health risk assessment

Non-carcinogenic risk Assessment focuses on evaluating the potential health risks posed by substances that do not cause cancer. Common terms used include EDI, HQ and HI. Carcinogenic Risk Assessment is concerned with assessing the likelihood of cancer development due to exposure to carcinogens. Estimating the probability of developing cancer over a lifetime due to exposure. The common assessment is known as ILCR. The following subsections are dedicated to the results and discussion of non-carcinogenic and carcinogenic human health risk assessment.

3.2.1. Non-carcinogenic human health risk assessment

Table 6 summarizes the estimated daily intake (EDI) of heavy metals Cr, Zn, and Fe in all samples calculated using Eq. 2. These were calculated according to the concentration of each heavy metal in each beer sample and the respective consumption rates. The estimated EDI in all sample ranges are Cr (0.5829–1.3901), Zn (0.0002–0.0052) and Fe (0.0025–0.0370) mg/kg/day. The total estimated mean EDI of Cr, Zn, and Fe were 0.9509, 0.0022, and 0.0189 mg/kg/day, respectively. In beer samples, the EDI decreases in the following order Cr>Fe>Zn. The mean EDI of the target metals Fe and Zn were below the provisional maximum tolerable daily intake (PMTDI) set by joint FAO/WHO [40,41] so they could not cause any negative health effects on the consumers. However, the mean EDI for Cr was above the recommended value of 0.2 set by FAO/WHO [24]; this might imply a risk for moderate and high beer consumers.

Table 7 shows the calculated HQ and HI by using Eq. 3 and Eq. 4, respectively. The results for HQ of Zn and Fe in all samples were below 1 (HQ<1), suggesting no non-cancer risk for the beer consumers. However, HQ value for Cr for all samples was greater than 1, which indicates

Table 5
The correlation coefficient of heavy metals in beer samples the $p>0.05$.

Heavy Metals	Zn	Fe	Cr
Zn	1	0.47	−0.067
Fe	0.47	1	−0.029
Cr	−0.067	−0.029	1

Table 6
EDI of heavy metals via the consumption of beer samples (mg/kg/day).

Sample code	**Cr**	**Zn**	**Fe**
S1	0.5829	0.0052	0.0370
S2	0.7099	0.0027	0.0025
S3	0.8453	0.0030	0.0181
S4	0.9275	0.0011	0.0112
S5	1.0828	0.0030	0.0124
S6	1.2286	0.0023	0.0263
S7	1.3126	0.0012	0.0114
S8	1.3715	0.0007	0.0133
S9	1.3901	0.0022	0.0355
S10	0.0580	0.0002	0.0214
Mean	0.9509±0400	0.0022±0.0014	0.0189±0.0090
PMTDI [40,41]	0.2	1	0.8

Table 7
Estimated HQ and HI for heavy metals in investigated beer samples.

Sample code	HQ			HI
	Cr	Zn	Fe	
S1	194.3	0.0173	0.053	194.847
S2	236.63	0.009	0.0036	236.643
S3	281.77	0.010	0.0258	281.806
S4	309.167	0.0037	0.016	309.187
S5	360.93	0.010	0.0177	360.958
S6	409.53	0.0077	0.0375	409.575
S7	437.53	0.0040	0.0163	437.550
S8	457.167	0.0023	0.019	457.188
S9	463.367	0.0073	0.0507	463.425
S10	19.33	0.0007	0.0305	19.361

that beer consumers are exceeding the non-cancer health guidelines. HI is the potential cumulative hazard from all heavy metals. In this study, which means the HI was above the limit value of 1. HI values exceeding 1 (HI > 1) suggest a potential risk of non-carcinogenic harm from exposure to toxic heavy metals through beer consumption [31]. Fig. 1 shows EDI and contribution of HI for heavy metal Cr, Zn and Fe. It is clear that concentration of Cr contribute to high amount of EDI and HQ which leads to to high contribution of HI.

3.2.2. Carcinogenic human health risk assessment

Fig. 2 shows the incremental lifetime cancer risk (ILCR) for Cr due to the consumption of beers calculated using Eq. 5. ILCR for Cr ranged from 0.029 (S10) to 0.695 (S9). The ILCR due to Cr contamination beer samples in order of increasing is S10<S1<S2<S3<S4<S5<S6<S7<S8<S9. The safe limit of ILCR of heavy metals set by the United States Environmental Protection Agency (USEPA) is a range of $1 \times 10^{-6} - 1 \times 10^{-4}$ [29,31]. If ILCR is below the safe limit, it means there is a low possibility of threshold cancer risk for consumers, and if it is above 1×10^{-4}, means a high possibility of threshold cancer risk for consumers. In this study, the mean ILCR for Cr in all beer samples was above 1×10^{-4}, indicating a high possibility of threshold cancer risk for consumers. A key limitation of this study is the small sample size, which may not adequately reflect the larger population. This could impact the strength of the study's conclusions. Future research should involve a larger sample size of both local and imported beer brands to achieve more conclusive results.

4. Conclusion

The heavy metals Cd, Cr, Zn, Pb, Fe and Cu were analyzed in beer samples consumed in Iringa municipal, Tanzania. In this study, levels of toxic and essential elements in beer samples were also estimated for

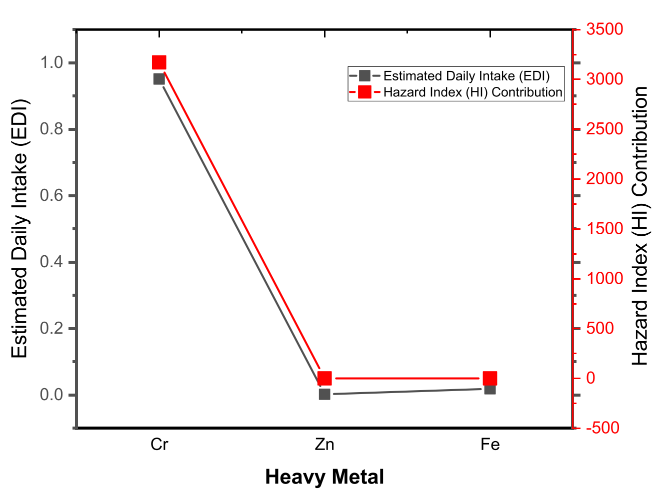

Fig. 1. EDI and Contribution of HI for heavy metal Cr, Zn and Fe.

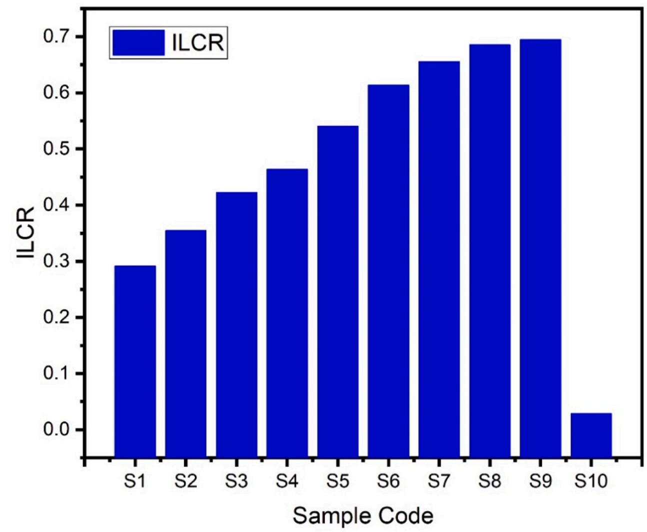

Fig. 2. ILCR due to Cr contaminations in beer samples.

human health risks. Generally, the concentration of heavy metals in beer samples was in increasing order: Zn<Cu<Fe<Cr. Cd and Pb were not detected in any beer sample. Zn and Cu were below the WHO limit. However, Fe and Cr were above the WHO limit. The total estimated mean EDI of Cr, Zn, and Fe were 0.9509, 0.0022, and 0.0189 mg/kg/day, respectively. The mean EDI of the target metals Fe and Zn were below the PMTDI set by joint FAO/WHO. However, the mean EDI for Cr was above the recommended value of 0.2 set by FAO/WHO. HQ and HI values above 1 for Cr indicated considerable non-carcinogenic health risk concerns via the consumption of beer. However, for Zn and Fe HQ and HI, there were less than 1, which shows no non-cancer health risk problems. ILCR ranged from 0.029 (S10) to 0.695 (S9). ILCR for all beer samples due to Cr contamination were above 1×10^{-4}, which indicates there might be a carcinogenic risk associated with this toxic metal (Cr) content and, hence, the possible health risk associated with cancer for frequent consumption of beer. As a result, industry participants and regulatory bodies are encouraged to consistently adhere to food and beverage standards from an ethical perspective to protect the health and well-being of beer consumers. Furthermore, conducting additional research that includes a wider selection of beer brands is essential to better understand the variability in heavy metal content across different products. This expanded research could help identify any potential sources of contamination that may be unique to certain brands or production processes.

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Authorship statement

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CRediT authorship contribution statement

Niwaeli Orgenes Eliaza: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Sifael Benjamin Malamla: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yohana Ramadhani Mabula:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Amos Vincent Ntarisa:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Data availability

Data will be made available on request.

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