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A Deterministic Risk Assessment of the Human Exposure to Cadmium, Lead and Chromium through the Consumption of Well and Bottled Water in Lusaka District, Zambia

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Abstract

The United Nation's Sustainable Development Goal Number Six is to 'Ensure availability and sustainable management of water and sanitation for all', which is an essential component for human survival. Access to safe drinking water is essential for health, a basic human right and a component of effective policy for health protection. Safe drinking water implies that the water does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. However, water is prone to contamination with heavy metals through natural and anthropogenic sources, making it unsuitable for human consumption due to the cumulative potential risks associated with the presence of heavy metals.

This study was conducted to assess the non-carcinogenic and carcinogenic risk of human exposure to cadmium, lead and chromium through the consumption of well and bottled water in Lusaka district of Zambia. Secondary data was used to determine the mean concentrations of heavy metals in well and bottled water in Lusaka District and to calculate the hazard index (non-carcinogenic risk) and cancer risk for the metals under study.

The results revealed that a hazard index for cadmium, lead and chromium in both well and bottled water was higher than 1, indicating adverse effect on human health over a lifetime of consumption. Similarly, the total cancer risk through exposure to cadmium and chromium in well and bottled water was 1.2×10^{-1} and 2.25×10^{-1}, respectively; higher than the safe threshold limit set by the United States Environmental Protection Agency (USEPA) of 1×10^{-4}.

The study concludes that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through the consumption of well and bottled water in Lusaka District. Further, the study concludes that there is a possible carcinogenic risk of exposure to cadmium and chromium through consumption of both well and bottled water. Owing to the proportion of both well and bottled water samples that exceeded the Zambia Bureau of Standards threshold limit, cadmium poses the greatest concern and requires intervention to reduce exposure. Therefore, it is recommended that heavy metal concentrations in drinking water should be periodically monitored to minimise health risks to consumers.

Keywords: *Carcinogenic risk, heavy metal pollution, human health risk assessment, non-carcinogenic risk, Zambia*

1.0 Introduction

Access to safe drinking water is essential for health, a basic human right and a component of effective policy for health protection. Safe drinking water implies that it does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (WHO, 2004). However, drinking water is prone to contamination by various hazards with microbiological and chemical hazards being the most significant (WHO, 2004).

Water contamination with heavy metals has serious long-term health effects on consumers, including cancer and organ damage (Godt *et al.,* 2006; WHO, 2010a). The ability of heavy metals to bio-accumulate in body tissues is of concern because exposure to even small doses over an extended period can result in negative health outcomes (Jaishankar *et al.,* 2014). The International Agency for Research on Cancer (IARC) has classified cadmium and chromium as group 1 carcinogens, and various reports have found that exposure to these compounds can lead to disruptions in tumour suppressor gene expression and damage repair processes (Banfalvi, 2011). Exposure to lead impairs the development of the brain and nervous system in children, increases the risk of high blood pressure, and kidney damage in adults, and causes miscarriages, stillbirths, premature births, and low birth weight in children if pregnant women are exposed (WHO, 2019). Heavy metals also induce oxidative stress, DNA damage, and cell death processes, resulting in an increased risk of cancer and cancer-related diseases (Hyuno and Young, 2015).

Lusaka District is the most urbanised town and the capital city of Zambia, with a population estimated at 2.6 million residents as of 2020 (ZSA, 2020). The district is built over a karstic dolomite aquifer, which serves as a source of underground drinking water, accounting for 61% of the total water supply within Lusaka District (Nachiyunde *et al.,* 2013). Until recently, siting and drilling of water wells and boreholes were unregulated and remain inadequately regulated to a larger extent (MoJ, 2018). This raises the possibility of accessing contaminated water through wells and boreholes for both domestic and commercial use.

Several studies have been conducted in Zambia, which have shown contamination of underground water with toxic heavy metals, including; cadmium, lead, chromium, arsenic, iron and copper (Nambeye, 2017: Nick *et al.,* 2010: Mucheleng'anga, 2007: Kampeshi, 2003: ZCSA, 2021). However, a search through various databases did not find a record of a study conducted to assess the risk of human exposure to cadmium, chromium and lead through consumption of well and bottled water in Zambia. Owing to the high concentrations of cadmium, lead and chromium in well and bottled water reported in previous studies conducted in Lusaka District and the adverse effects of exposure to these heavy metals, it was imperative to assess the health risk posed to consumers and, if necessary, propose remedial measures.

2.0 Materials and Methods

2.1 Study Design, Data Collection and Analysis

This was a quantitative risk assessment study based on the Codex Alimentarius Commission (CAC) risk analysis framework which includes four distinct steps namely, Hazard Identification, Hazard Characterisation, Consumer Exposure Assessment and Risk Characterisation.

This study collected data from a literature review from electronic databases, including Google Scholar, Mendeley and PubMed (NLM). The study also used grey literature from conference proceedings and reports from the government institutions and non-governmental organisations, which were accessed from Google Search Engine. Key search terms included 'heavy metals in water', 'chemical analysis of water', 'Carcinogenic risk', 'heavy metal pollution', 'non-carcinogenic risk', 'Lead', "Cadmium', 'Chromium', 'Zambia.' Two key previous studies formed a source of mean concentrations of heavy metals in well and bottled water in Lusaka District (Nambeye, 2017: ZCSA, 2021). The Laboratory analysis for both well and bottled water in the previous studies were conducted according to the American Public Health Association (APHA), Association of Official Agricultural Chemists (AOAC) and the International Standards Organisation (ISO) test procedures, and the results were interpreted according to the Zambian standards for drinking water (Nambeye, 2017: ZCSA, 2021).

The secondary data collected from a literature review was used to feed into deterministic chemical risk assessment equations to estimate human exposure to heavy metals through the consumption of well and bottled water. Risk estimation for the non-carcinogenic and carcinogenic risk exposure to heavy metals was conducted by calculating the hazard index and cancer risk, respectively, based on the United States Environmental Protection Agency (USEPA, 2016).

2.2 Health Risk Assessment

2.2.1 ExposureAssessment

The Chronic Daily Intake (CDI) is the exposure expressed as mass of a substance ingested per unit body weight per unit time, averaged over a long period of time (Pawełczyk, 2013). This study adopted the USEPA formula for calculating the CDI (USEPA, 2016) as shown in Equation 1:

$$CDI = (C \times IR \times EF) / BW \quad \text{(Equation 1)}$$

Where: CDI is chronic daily intake (mg/kg/day)

C is concentration of contaminant (mg/l)

IR is intake rate of contaminant (l/day)

EF is exposure factor (unitless)

BW is body weight (kg)

2.2.2 Non-carcinogenic Risks

The non-carcinogenic risk refers to the potential for adverse systemic or toxic effects caused by exposure to non-carcinogenic elements of concern (Mohammadi *et al.,* 2019). It is estimated using the hazard quotient, which compares the chronic daily intake of heavy metals with the Reference Dose (RfD). The reference dose represents a daily oral intake rate that is estimated to pose no appreciable risk of adverse health effects, even to sensitive populations, over a 70-year lifetime (USEPA, 2005). A hazard quotient value below 1 implies that there is no adverse effect on human health, while a value above 1 implies an adverse effect on human health (USEPA, 2016). The non-carcinogenic risk of exposure to cadmium, lead and chromium was calculated using the proposed formulae for both Hazard Quotient (HQ) and Hazard Index (HI) (USEPA, 2005) as shown in Equation 2:

$$HQ = CDI / RfD \quad \text{(Equation 2)}$$

$$HI = \sum HQ$$

Where; HQ is hazard quotient

HI is hazard index, representing the sum of HQs for cadmium, lead and chromium

CDI is chronic daily intake (mg/kg/day)

RfD is oral reference dose (mg/kg/day)

2.2.3 Carcinogenic Risks

Carcinogenic or cancer risks (CR) is defined as 'the incremental probability of an individual to develop cancer, over a lifetime, as a result of exposure to a potential carcinogen' (USEPA, 2016). It is a product of chronic dietary exposure to a toxic element and the Cancer Slope (CS) factor, defined as a measure of cancer risk from a lifetime exposure to an agent (USEPA, 1991). The safe threshold limit for cancer risk is 1×10^{-4} to 1×10^{-6} (USEPA, 2012). Risk higher than 1×10^{-4} is interpreted as a chance of 1 in 10,000 people developing cancer during their lifetime from the exposure being evaluated and is considered unacceptable, requiring intervention and remediation (USEPA, 2005). The carcinogenic risk was calculated only in respect of cadmium and chromium because there is no validated cancer slope factor set for lead. The carcinogenic risk of exposure to cadmium and chromium was estimated using the formulae proposed by USEPA (2005), as shown in Equation 3:

$$CR = CDI \times CS \ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 3)}$$

$$TCR = \sum CR$$

Where; CR is a cancer risk,

TCR is total cancer risk, representing the sum of CRs for cadmium and chromium

CDI is chronic daily intake (mg/kg/day)

CS is the oral cancer slope factor $(mg/kg/day)^{-1}$

2.3 Ethical Considerations

Authority to conduct research was obtained from the University of Zambia Biomedical Research Ethics Committee (Ref No. 2169-2021) and the National Health Research Authority (Ref No. NHRA000023/28/12/2021). In addition, written permission was obtained from ZCSA (Ref No. ZCSA/ED/10/04/21) to use water analysis data. Further, the names of bottled water brands and the identities of their manufacturers have not been disclosed to ensure confidentiality.

3.0 Results

3.1 Concentration of Heavy Metals in Well Water

The mean concentrations of cadmium, lead and chromium in well water was 0.62 mg/l, 0.04 mg/l and 0.39 mg/l, respectively as shown in Table 1. Further, the proportion of samples that exceeded the ZABS threshold limit was 100%, 7% and 93% for cadmium, lead and chromium, respectively.

Table 1. Concentration of Heavy Metals in Well Water

Metal	Number of samples	Samples above threshold limit	Proportion above threshold limit (%)	Mean concentration (mg/l)	Maximum limit (Zambian Standard)
Cadmium	14	14	100	**0.62**	0.003*
Lead	14	1	7	**0.04**	0.01*
Chromium	14	13	93	**0.39**	0.05*

Source: *Nambeye (2017): ZABS (2010)**

3.2 Concentration of Heavy Metals in Bottled Water

The mean concentration of cadmium, lead and chromium was 1.2 mg/l, 1.16 mg/l, and 1.03 mg/l, respectively as shown in Table 2. Cadmium had the highest proportion of samples (82%) that exceeded the ZABS threshold limit, while lead and chromium had 14% and 11% of the samples exceeding the threshold limit, respectively (ZCSA, 2021).

Table 2. Concentration of Heavy Metals in Bottled Water

Metal	Number of samples	Samples above threshold limit	Proportion above threshold limit (%)	Mean concentration (mg/l)	Maximum limit (mg/l) (Zambian Standard)
Cadmium	254	209	82	**1.2±0.136**	0.003*
Lead	254	36	14	**1.16±0.944**	0.01*
Chromium	254	28	11	**1.03±0.132**	0.05*

Source: *ZCSA (2021): ZABS (2000) **

3.3 Water Consumption Pattern

This study adopted the default water consumption values proposed by the International Programme on Chemical Safety (IPCS) and adopted by the WHO for different categories of consumers as shown in Table 3 (WHO, 2003: ATSDR, 2005):

Table 3. Water Consumption Patterns

Category	Weight (kg)	Consumption (l/day)
Adult males	70	2
Adult females	70	2
Children below 10 years	16*	1*

Source: *WHO (2003): ATSDR (2005) **

3.4 Human Health Risk Assessment

3.4.1 Hazard Identification

Heavy metals are naturally occurring elements with a high atomic weight and a density at least five times greater than water. However, being a heavy metal has little to do with density but concerns chemical properties that affect humans, animals and the environment (Duruibe *et al.,* 2007). Their multiple industrial, domestic, agricultural, medical, and technological applications have led to their wide distribution, raising concerns over their potential effects on human health and the environment (Tchounwou *et al.,* 2012). Reported sources of heavy metals in the environment include industrial waste originating from metal plating, mining activities, smelting, battery manufacturing, tanneries, petroleum refinery, paint manufacturing, pesticides, pigment manufacturing, printing or photographic industries and fertiliser production (Paolo *et al.,* 2010). Although heavy metals are naturally occurring elements that are found throughout the earth's crust, most environmental contamination and human exposure result from anthropogenic activities (He *et al.,* 2005).

The main pathways for human exposure include ingestion through food and water, inhalation and direct skin contact (Tchounwou *et al.,* 2012: Duruibe *et al.,* 2007). Once ingested, they can bio-accumulate in the body for a long period until they reach toxic levels. For instance, cadmium has a long half-life of 25 to 50 years in the kidneys, lead can persist up to 30 years in the bones, and chromium has a half-life of up to 10 years in epidermal tissues such as hair, bones, liver, kidney, spleen and lungs (Kabata-Pendias *et al.,* 2015: Petersen *et al.,* 2000). All age groups can be affected, but children are more vulnerable partly because their defence mechanisms may not be fully developed and their high absorption rate for some heavy metals (Westrell *et al.,* 2006). Kabata-Pendias *et al.,* (2015), observed that cadmium absorption appeared to be higher in newborns and infants, in contrast to adults, independent of iron status. The concentration of chromium was also relatively higher in newborn children than in adults. Although water consumption is lower among children compared to adults, they have higher ingestion in relation to their body weight, which makes them more sensitive to contaminants (Westrell *et al.,* 2006).

3.4.2 Hazard Characterisation

The toxicity of heavy metals depends on several factors, including the dose, route of exposure, chemical species, age and gender of exposed individuals (Godt *et al.,* 2006). Cadmium, chromium and lead rank among the priority heavy metals that are of public health significance because of their high degree of toxicity (Tchounwou *et al.,* 2012). These metallic elements are considered systemic toxicants that are known to induce multiple organ damage, even at lower levels of exposure (WHO, 2019). They are also classified as human carcinogens (known or probable) according to USEPA and the International Agency for Research on Cancer (Tchounwou *et al.,* 2012). Research has documented the characteristics and adverse effects of exposure to the three evaluated heavy metals as follows:

Cadmium

The None Observable Adverse Effects Level (NOAEL) for cadmium is 0.001 mg, Low Observable Adverse Effects Level (LOAEL) is 100 mg, and the lethal dose (LD 50) is 350 to 3500 mg (Krajnc, 1987). According to Godt *et al.,* (2006), exposure to cadmium causes short-term effects that include nausea, vomiting, diarrhoea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure. Long-term effects include kidney damage, testicular necrosis and prostate cancer, pneumonitis and the destruction of the mucous membrane in the reproductive and respiratory systems (Water Quality Association, 2013).

Lead

There is no known 'safe' blood lead concentration as even blood lead concentrations as low as 5 µg/dl may be associated with decreased intelligence in children, behavioural difficulties and learning problems (WHO, 2010b), although blood lead levels of 10 µg/dl in children and 25 µg/dl in adults are what are considered as toxic (Bellinger *et al.,* 1991: Roscoe *et al.,* 2002). This lack of an indication of a threshold level for key effects of lead, based on the dose-response analysis, led the Joint FAO/WHO Expert Committee on Food Additives (JECFA) to conclude that a new Provisional Tolerable Weekly Intake (PTWI) considered as health-protective could not be established (WHO, 2019). Further, WHO (2019) found that exposure to lead impairs the development of the brain and nervous system in children, increases the risk of high blood pressure and kidney damage in adults and causes miscarriages, stillbirths, premature births and low birth weight children if pregnant women are exposed. Other adverse effects include joint and muscle pain, headache, trouble concentrating, memory problems and mood changes (CDC, 2022).

Chromium

Although several studies have been conducted on animal subjects to assess the severity of chromium exposure, the NOAEL, LOAEL and LD50 for chromium have not been established. However, in a study conducted by Zhang and Lee (1987) that found exposure levels of 0.57mg/kg/day, associations were found between drinking the contaminated water and oral ulcer, diarrhoea, abdominal pain, indigestion, and vomiting. Another study in China reported an increase of stomach cancer mortality in the residents of small villages in the Liaoning province, where the drinking water was heavily contaminated with chromium (VI) (Sun et al, 2015). Other effects of exposure to chromium include increased incidence of liver and lung cancers and increased incidence of gastrointestinal and dermatological complaints (Linos *et al.,* 2011: Sharma *et al.,* 2012).

Based on experimental data and dose-response relationships, Health Guidance

Values (HGV) for heavy metals in drinking water have been set, which vary from country to country. For example, in the United States, the maximum allowable amount of a contaminant in drinking water (MCL) is 0.005mg/l for cadmium, 0.015mg/l for lead and 0.1mg/l for chromium (USEPA, 2021). Zambia has adopted the WHO threshold limit values of 0.003mg/l for cadmium, 0.01 mg/l for lead and 0.05 mg/l for chromium (ZABS, 2010).

3.4.3 Exposure Assessment and Risk Characterisation

Chronic Daily Intake

The lifetime Chronic Daily Intake (CDI) for cadmium was 0.018mg/kg/day and 0.034mg/kg/day for well and bottled water, respectively, while that of lead was 0.001mg/kg/l and 0.033mg/kg/l for well and bottled water, respectively. For chromium, the CDI was 0.011mg/kg/day and 0.029mg/kg/day for well and bottled water, respectively. All the metals analysed had CDIs above the reference dose in both well and bottled water. Table 4 shows the CDI and reference dose for the heavy metals under study.

Table 4. Lifetime Chronic Daily Intake for Heavy Metals

Metal	Well Water (mg/kg/day)	Bottled Water (mg/kg/day)	Reference Dose (mg/kg/day)
Cadmium	0.018	0.034	0.0005**
Lead	0.001	0.033	0.0004*
Chromium	0.011	0.029	0.003**

Source: *ATSDR (2005) *: USEPA (1991)***

Non-carcinogenic Risk

The calculated lifetime Hazard Quotient (HQ) for cadmium, lead and chromium in well water was 36.00, 2.50 and 3.67, respectively, while the HQ of the same heavy metals in bottled water was 68.00, 82.50 and 9.67, respectively. The Hazard Index (HI) for cadmium, lead and chromium in well water was 42.17, while that of bottled water was 160.17.

Carcinogenic Risk

The calculated lifetime Cancer Risk (CR) for cadmium and chromium in well water was 1.1×10^{-1} and 6.0×10^{-3}, respectively; while that of bottled water was 2.1×10^{-1} and 1.5×10^{-2}, respectively. The Total Cancer Risk (TCR) for cadmium and chromium in well water was 1.2×10^{-1} while that of bottled water was 2.25×10^{-1} as show in Table 5.

Table 5. Lifetime Carcinogenic Risk

Parameter	Well Water		Bottled Water	
	Cadmium	**Chromium**	**Cadmium**	**Chromium**
CDI (mg/kg/day)	0.018	0.011	0.034	0.029
CS $(mg/kg/day)^{-1}$	6.1**	0.5*	6.1**	0.5*
CR	1.1×10^{-1}	6.0×10^{-3}	2.1×10^{-1}	1.5×10^{-2}
TCR	**1.2×10^{-1}**		**2.25×10^{-1}**	

Source: *Stern (2010) *: USEPA (1991)***

4.0 Discussion

Exposure to lead, cadmium, chromium and other heavy metals through drinking water is a public health concern, and it is thus, important that health risk assessments are investigated.

The non-carcinogenic risk results show that cadmium had the highest hazard quotient (HQ) in well water at 36, followed by chromium at 3.6 and lead at 2.5. In bottled water, the lead had the highest HQ at 82.5, followed by cadmium at 68 and chromium at 9.6. The combined HQ for cadmium in both well and bottled water was higher than that of lead and chromium combined, indicating that cadmium posed the greatest risk among the 3 metals analysed. However, all the metals had HQs above 1, implying that water consumers are exposed to heavy metals in concentrations higher than the reference dose and thus, likely to experience negative health outcomes associated with exposure to these metals over a lifetime of water consumption (USEPA, 2016). The higher HI in bottled water compared to the well water indicates a higher exposure to cadmium, lead and chromium in individuals consuming bottled water. These results are consistent with other studies that found high HI in underground water in Nigeria (Onyinyechi *et al.,* 2018) and Pakistan (Khan *et al.,* 2015).

Regarding carcinogenic risks, the cancer risk (CR) due to exposure to cadmium and chromium in well water was 1.1×10^{-1} and 6.0×10^{-3}, respectively, while the CR in bottled water was 2.1×10^{-1} and 1.5×10^{-2}. The total cancer risk (TCR) through exposure to both cadmium and chromium was 1.2×10^{-1} and 2.25×10^{-1} in well and bottled water, respectively. The TCR for cadmium and chromium in both well and bottled water was higher than the threshold of 1×10^{-4}, thus, implying a risk of causing 1 case of cancer for every 10,000 people for those who consume well water and 2 cases of cancer for every 10,000 people for those who consumed bottled water, over a lifetime of water consumption. The results also show that cadmium was the biggest contributor to the TCR in both well and bottled water at 1.1×10^{-1} and 2.1×10^{-1}, respectively.

The results indicate widespread underground water contamination with cadmium, lead and chromium, which could be attributed to anthropogenic and, to a lesser extent, natural water pollution. Moreover, the majority of the producers of bottled water are located in the industrial area, from where they extract underground water, while other producers are located in areas such as Lusaka West and Makeni, which were previously used for agricultural activities. Therefore, there is a possibility of underground water contamination from toxic wastes emitted from other industries and residuals from fertilisers used in the farms. The results further showed that there is heavy metal contamination of bottled water indicative of possible anthropogenic water pollution of specific water sources. Although ZCSA (2021) did not state the reasons why there were high levels of heavy metals in bottled water, a possible explanation could be that it is an indication of inadequate water purification techniques during production since bottled water usually undergoes treatment before packaging. This further implies that the purification processes for bottled water including reverse osmosis, ultraviolet treatment and ozone treatment, are either not used at all or are failing to remove the heavy metal contamination. Additionally, these findings may suggest that certain bottled water brands may be packaged without adherence to the standard purification procedures. For this reason, there is a need to evaluate the effectiveness of existing water purification techniques being used by manufacturers, to take remedial measures and to conduct further investigations to determine the exact sources of heavy metals.

Further, interventions to address the high content of heavy metals in drinking water, particularly cadmium whose HQ was very high, need to be implemented to ensure that drinking water meets regulatory standards. These measures could include the use of improved water purification techniques that lower the levels of heavy metals in drinking water, such as reverse osmosis, ion exchange and lime softening. The findings of this study agree with other studies conducted in Nigeria by Salihu *et al.,* (2019) and in Iran by Majid *et al.,* (2017), Alidadi *et al.,* (2019) and Mohammadi *et al.,* (2019) that found high cancer risks in drinking water. Ahmed and Mokhtar (2020) also suggested the application of additional water purification techniques to reduce the levels of heavy metals in drinking water, where consumers are at risk of exposure.

Uncertainty of Risk/Limitations

There is the possibility of uncertainties that may not be taken into account and could be considered as a limitation for the validity of this risk estimation.

Firstly, the body weights and water consumption patterns for different categories of consumers and seasons of the year were not estimated for the people who live in the Lusaka District. The use of WHO default values may, therefore, result in over or underestimation of the risk. Secondly, the study used the mean concentrations of heavy metals in the water to calculate the CDI irrespective of the proportion of samples that exceeded the threshold limits for the metals under study.

For this reason, the few samples with elevated levels of lead and chromium in bottled water could have contributed to high mean concentrations and hence, overestimating the risk. Thirdly, the carcinogenic risk for exposure to lead could not be calculated because there is no validated Carcinogenic Slop Factor (CSF) set for the metal. Finally, the health risk was only assessed using the three heavy metals under study but drinking water also contains other chemicals that may have an adverse effect on health. Therefore, the level of risk from drinking water may be higher than the estimated risk in this study.

Conclusion

This study evaluated the non-carcinogenic risk of exposure to cadmium, lead and chromium through consumption of well and bottled water. Results indicate that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through the consumption of bottled water in Lusaka District.

Further, results indicate that there is a possible non-carcinogenic risk of exposure to cadmium, lead and chromium through the consumption of well water in George compound of Lusaka District. This is because the calculated hazard quotients in both well and bottled water were above the threshold limit of 1. This is attributed to the high concentration of heavy metals in both well and bottled water.

This study also evaluated the carcinogenic risk of exposure to cadmium and chromium, which are known or probable carcinogens, through the consumption of well and bottled water in Lusaka District. Results indicate that there is a possible carcinogenic risk of exposure to cadmium and chromium through consumption of both well and bottled water with an estimated risk of 1.1×10^{-1} and 2.1×10^{-1}, respectively, implying a chance of causing 1 case of cancer for every 10,000 people for those who consume well water and 2 cases of cancer for every 10,000 people for those who consumed bottled water, over a lifetime of water consumption. Owing to the proportion of samples that exceeded the threshold limit set by the Zambia Bureau of Standards for the 3 evaluated heavy metals, cadmium poses the greatest concern and requires intervention to reduce exposure. Therefore, there is a need for relevant institutions to continue monitoring the levels of heavy metals in drinking water to protect the public from exposure to unacceptable levels of heavy metals.

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Conflicts of Interest: The authors declare no conflict of interest.

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