British Journal of Environmental Sciences 11 (4), 1-21, 2023
Print ISSN: 2055-0219(Print)
Online ISSN: 2055-0227(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development–UK

Assessment of Health Risks Due to the Presence of Heavy Metals in Drinking Water Sources the in Chingola District of the Copperbelt Province of Zambia

Jimmy J Daka[1*]; Able Mucheka Kafwembe[1].
School of Natural and Applied Sciences, Mulungushi University, Zambia.
Department of Chemistry and Biology
Corresponding author: jdaka@mu.edu.zm

doi: https://doi.org/10.37745/bjes.2013/vol11n4121 Published August 26, 2023

Citation: Daka J.J. and Kafwembe A.M. (2023) Assessment of Health Risks Due to the Presence of Heavy Metals in Drinking Water Sources the in Chingola District of the Copperbelt Province of Zambia, British Journal of Environmental Sciences 11 (4), 1-21

ABSTRACT *Water contamination is one of the issues preventing access to clean water. Waterbody poisoning with heavy metals is particularly concerning. This study aimed to ascertain the concentrations of heavy metals in the drinking water sources in the Chingola District of Zambia and assess the health risks based on carcinogenic and non-carcinogenic indices. The study was cross-sectional in design. In the dry season, water samples were obtained, and in the wet season, an equal number of water samples were collected. All the water samples from all sources were analysed for heavy metals with Inductively Coupled Plasma (ICP -MS) Mass spectrometer was used to analyse heavy metals. Nickel contents in numerous water sources exceeded the maximum allowable values of 0.0012 to 0.2144 mg/L. Each water sample had levels of chromium and cadmium below the detection threshold, except for three sampling sites. Drinking water from the tap, open well, shallow well, and borehole had differing median amounts of arsenic, copper, zinc, and nickel, and this difference was statistically significant ($p < 0.05$). Arsenic, copper, zinc, and nickel median concentrations varied between the dry and wet seasons, and this variation was statistically significant ($p < 0.05$). Both carcinogenic and non-carcinogenic health indices (HI) were below the threshold values, though some individual sources may have shown levels beyond the upper limit of concentration.*

KEYWORDS: heavy metals, drinking water, water sources, carcinogenic health risk, pollution.

INTRODUCTION

Chingola's water supply is provided by *Mulonga* Water and Sewerage Company (MWSC). MWSC operates two water treatment plants in Chingola, one of which is located along the *Kafue River* and the other within *Nkokola* Copper Mine (KCM's) *Nchanga* mine. The raw water supply for the MWSC treatment plant at *Nchanga* mine is a reservoir that is operated by KCM and also used in their operations. The reservoir receives a mixture of water from the underground mine and

water from the Kafue River. In Chingola, the Kafue River and its tributaries receive highly polluted discharges of effluent from local mining operations, which contaminate the water sources of communities and lead to serious incidents of illness. Mining pollution also causes excessive silt damping in rivers and streams, which has a devastating impact on aquatic ecosystems and agriculture.

The ongoing pollution of the Kafue River and its tributaries make it nearly impossible for the water utility in Chingola, *Mulonga* Water and Sewerage Company, to treat water to meet ZABS drinking water quality standards, and the prioritization of water use for the mines over domestic needs causes significant interruptions to the water supply. As a result, the main domestic water supply for about 108,086 out of the 218 000 total population of Chingola may be compromised (ZAMSTEP 2022).

The current situation in Chingola shows how important it is for our water governance institutions to be active and accountable. Addressing industrial water pollution and the poor quality of water supply in Chingola requires a well-coordinated and immediate response from the Zambia Environmental Management Agency (ZEMA), the Water Resources Management Authority (WARMA), the National Water Supply and Sanitation Council (NWASCO), *Mulonga* Water and Sewerage Company (MWSC), the Chingola District Council, and the Ministry of Health (MoH).

A sampling campaign of the Kafue River carried out in 2012 found that the most polluted segment of the river was located in the Copperbelt, a finding that was attributed to mining and other industrial activities in the area (Sracek *et al* 2012). The principal source of contamination is the *Mushishima* stream in Chingola, a tributary of the Kafue River, which receives overflow from the tailings retention pond and pollution control dam of Konkola Copper Mine's (KCM) Nchanga mine (Sracek *et al* 2012).

Aim and Rationale for the Research

This study set out to look into the prevalence of heavy metals in nearby water sources surrounding the mining area of Chingola that might be impacted by mining activity. Reference locations (virgin water sources) were sampled as a control in places far from mining activities. The study also attempted to determine how the presence of heavy metals may pose health hazards for residents in terms of the health hazard index (HI), carcinogenic risk (CR index), and incremental lifetime carcinogenic risk (ILCR) the heavy metals may pose to residents consuming such water from those sources. Then, statistically, the research aimed at comparing the heavy metal presence between areas around the mining area and the set references (virgin water sources). This was to ascertain if there was any difference between the two sources of water for the people of Chingola that was significant as a result of mining activities or not. The rationale for the study was to highlight the heavy metal contamination that comes with mining activities and the need for vigorous water purification for utility companies supplying water to areas around the mines. The information from the research could also be used as a reference point for possible new areas where metal mining may need to be undertaken. Such activities may come with health risks; hence, remediation measures are necessary for new exploitation. This is evident in the work by Daka and Kamanga

2023, which established that the tailing damp site leached in the course of the Mufulira River in a town in the southern part of Chingola. Shan et al. (2022) reported hazardous levels of heavy metals in underground water in the mine areas of Joghatai, Iran. Monday et al. (2022) equally showed that underground water in mining districts in Nigeria showed carcinogenic toxic levels due to heavy metals. Therefore, Chingola being one of the oldest Zambian mining towns, no such study had been conducted before in this region, hence the need to evaluate the presence of heavy metals, assess the health hazard risk, and assess other related health indexes due to such metals.

METHODOLOGY

Study Area

This study took place in Zambia's Copperbelt Province's Chingola District. It is located at the following coordinates: 12° 32' 0" South, 27° 51' 0" East (Google Earth Map). It shares borders with Chililabombwe at the Kafue River in the North, Solwezi at the *Mushingwe* Stream in the Northwest, *Lufwanyama* in the Southwest, and Kalulushi at the Musenga in the South. It has a total surface area of 1,676 km^2. 60% of the population resides in highly populated metropolitan areas, with a projected population of 217,816 for 2016 and an annual growth rate of 2.9%. (CSO, 2011). The Mulonga Water and Sewerage Company provides piped water for urban neighbourhoods, whereas heavily populated urban areas (compounds) rely on a combination of shallow wells and piped water. Rural areas rely heavily on shallow wells as their primary source of subsurface water.

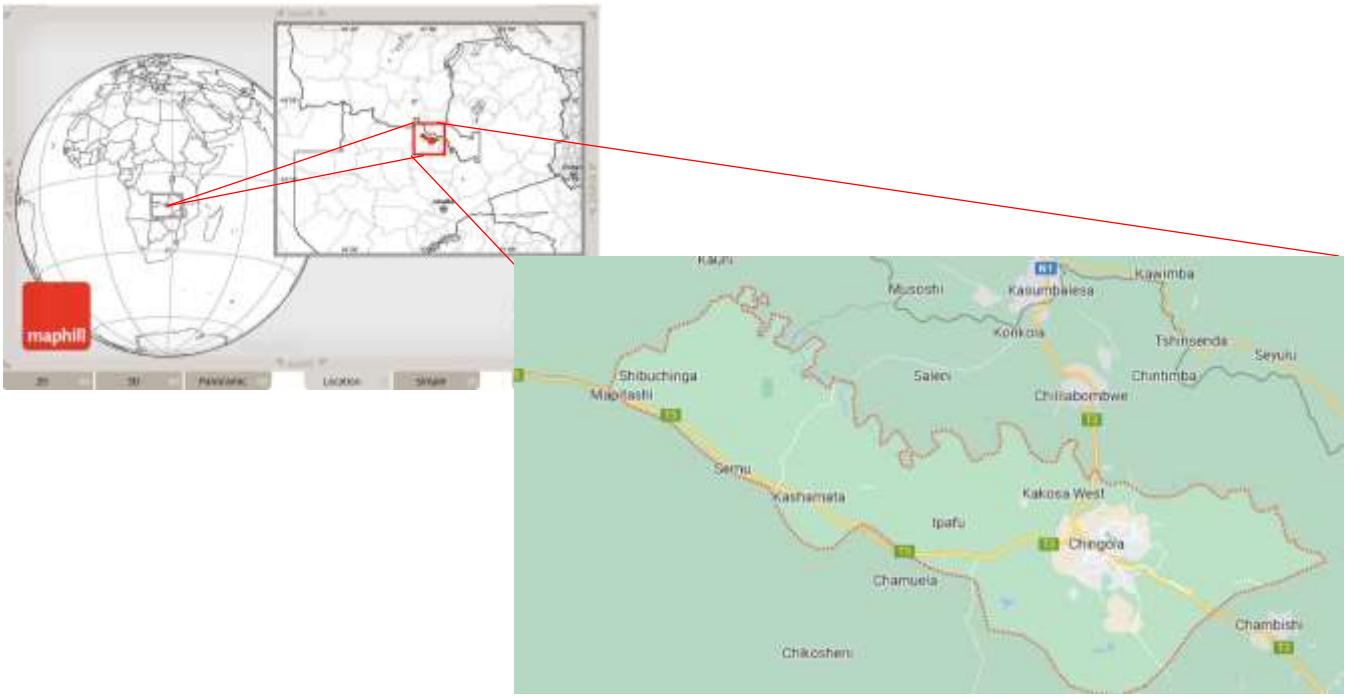

Figure1: Map of Chingola about the world and Zambia (google 2023 and Maphili 20230

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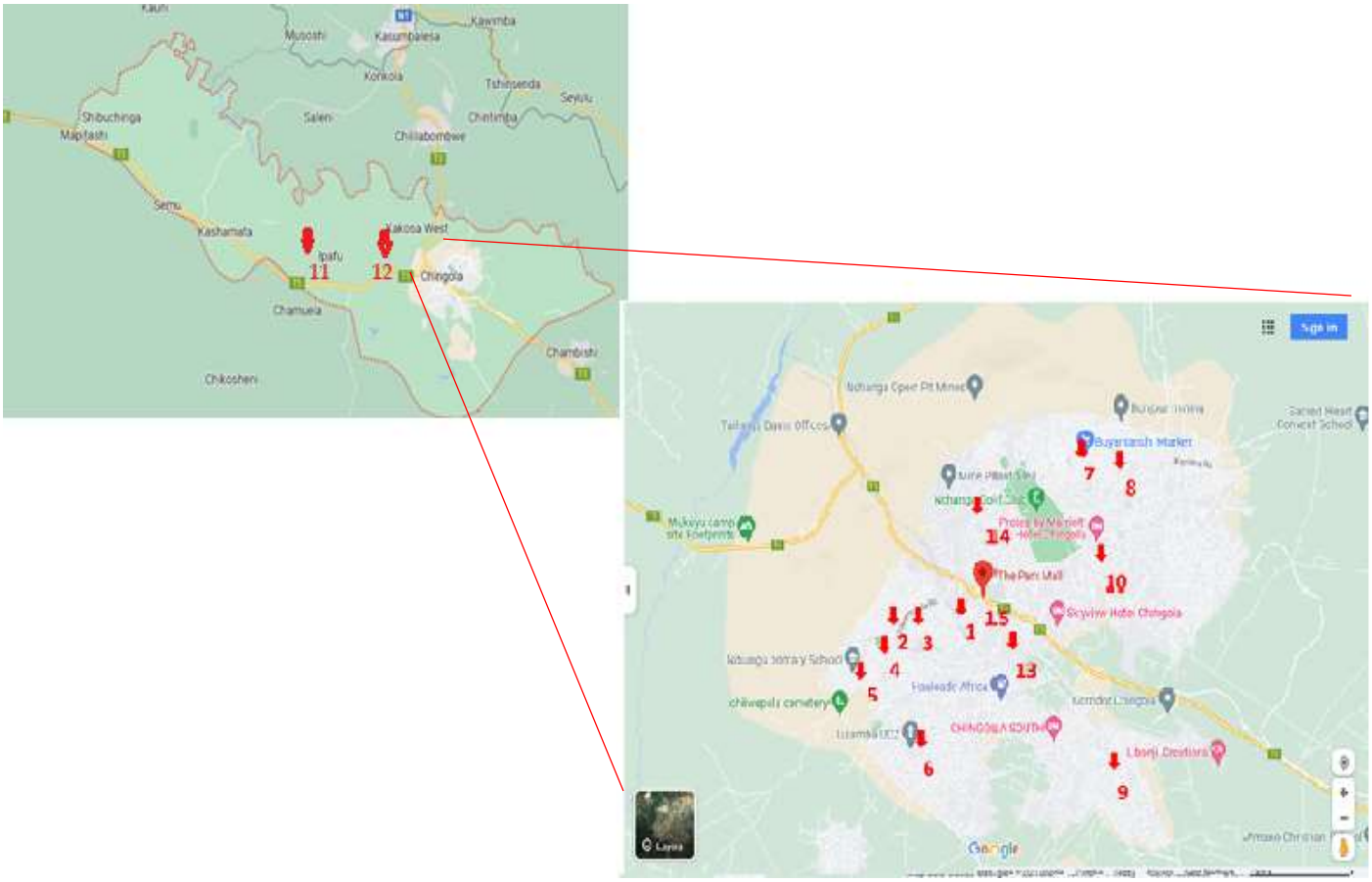

Fig. 2: Map of Chingola District showing names of proposed water sampling locations. Source: https://www.google.com/maps/place/Chingola/@-12.4792707,27.4253074,10z/data.

Study Design

This research was cross-sectional in nature. It happened all at once, or just briefly. Data was gathered at one particular time point to offer a "snapshot" of the outcome and the features connected with it at that particular time. Tap and subsurface water source samples were both taken.

Sample size calculation

A total of 30 x 3 samples were taken to evaluate seasonal fluctuations in the amounts of heavy metals.

Sampling and data collection

While samples of urban groundwater were taken from urban areas within a 10-kilometre radius of the mining environment, the furthest being 68 kilometres, samples of tap water were taken from urban regions where the water utility business provides service. Three borehole samples and seven shallow protected well samples were taken from the ten urban groundwater samples that were intended. Rural regions that were remote from the mining environment were used to gather groundwater samples. The closest rural sampling site is 15 kilometres away.

Following the selection of a zone, a sample size was chosen using simple random sampling once more, this time utilising a sampling frame of households. Households with any form of water supply made up the whole sample frame for zones. Both urban groundwater sources and tap water sources followed the same rules. 30 triplicate ml water samples were taken. They were divided into 15 triplicates of 100 ml of water samples taken in the wet season in the months of November and December, while the other 15 triplicates were obtained between September and October during the dry season. In both procedures followed by Cobbina *et al* (2015), the water samples were taken in sterile 1-litre polyethene bottles. To preserve the water sample using the technique employed by Muhammad *et al* (2011), a 1 mL drop of 5% nitric acid will be applied right away.

Sample digestion was performed to guarantee that organic contaminants were eliminated from the samples and to avoid interference with the analysis. One of the storage procedures is sample digestion, which releases metals into the analytical solution and prevents bacterial activity in the sample. In the technique of Obiri *et al* (2016), the materials were digested using strong nitric acid. Using Whatman1 filter paper, water was filtered before being consumed. To a 100 ml sample of water in a beaker, concentrated nitric acid (5 ml) was added. This was heated on a hot plate to boil for approximately 40 minutes, or until its volume was reduced to 10 ml. Then it was allowed to cool. Then inductively coupled plasma mass spectroscope was used to analyse e presence of heavy metals.

DATA AND ANALYSIS OF RESULTS

General Overview of Data

Because the quantities of heavy metals in water were skewed, the median and mean were used to report the concentrations. The measurements were made in milligrams per litre. Thirty (in triplicate) samples of water were examined, broken down as 15 by 3 in each season. The drinking water requirements of the Zambia Bureau of Standards (ZABS) and other worldwide standards were compared. The averages of the triplicate samples could be understood as shown in tables 1.1 and 1.2 below, representing the wet and dry seasons of the region.

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Table 1.1 Showing average values of concentration of various metals in sampled sites in a wet session.

SAMPLE SITE	TYPE OF SOURCE	AS mg/L	Bi mg/L	Co mg/L	Ni mg/L	Pb mg/L	Sb mg/L	Se mg/L	Te mg/L	Cu mg/L	Zn mg/L
1	A	0.0063	0.0104	0.0009	0.1991	<0.0001	<0.0001	0.0258	<0.0001	0.003	0.0001
2	B	0.0001	<0.0001	<0.001	0.2144	<0.0001	<0.0001	0.0141	<0.0001	0.0005	0.00011
3	B	<0.0001	0.0102	0.0044	0.2108	<0.0001	<0.0001	0.0046	<0.0001	0.0001	0.0002
4	B	<0.0001	0.0002	0.0046	0.1769	<0.0001	<0.0001	0.0073	<0.0001	0.0025	0.0001
5	C	<0.0001	0.0042	0.0034	0.2009	<0.0001	<0.0001	0.0046	<0.0001	0.0125	0.0021
6	A	<0.0001	0.0034	0.003	0.1713	<0.0001	<0.0001	0.0055	<0.0001	0.0023	0.00011
7	C	<0.0001	0.007	0.0019	0.2015	<0.0001	<0.0001	0.0066	<0.0001	0.0056	0.0021
8	C	<0.0001	0.0163	0.0026	0.104	<0.0001	<0.0001	0.0087	<0.0001	0.00121	0.0014
9	B	<0.0001	0.0208	0.0032	0.1203	<0.0001	<0.0001	0.0068	0.0012	0.0012	0.0009
10	B	<0.0001	0.0046	0.005	0.1717	<0.0001	<0.0001	0.0088	0.0069	0.0052	0.0001
11	C	<0.0001	0.0012	0.0032	0.0156	<0.0001	<0.0001	0.012	<0.00001	0.00251	0.0011
12	B	<0.0001	0.0009	0.0006	0.0325	<0.0001	<0.0001	0.0052	<0.0001	0.0025	0.0011
13	C	<0.0001	0.0018	0.0009	0.0144	<0.0001	<0.0001	0.0121	<0.0001	0.0011	0.0023
14	A	0.0002	0.0025	0.0059	0.0012	<0.0001	<0.0001	0.0002	<0.0001	0.0589	0.0009
15	D	<0.0001	<0.0001	0.00012	0.0325	<0.0001	<0.0001	0.0021	<0.0001	0.00089	0.0002
Mean		**0.0022**	**0.006423**	**0.002648**	**0.124473**			**0.008293**	**0.00405**	**0.006667**	**0.000855**
Median		**0.0002**	**0.0042**	**0.0030**	**0.1713**			**0.0068**	**0.0006**	**0.0025**	**0.0009**

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Table 1.2 Showing average values of concentration of various metals in sampled sites in dry session.

SAMPLE SITE	TYPE OF SOURCE	AS mg/L	Bi mg/L	Co mg/L	Ni mg/L	Pb mg/L	Sb mg/L	Se mg/L	Cr mg/L	Cu mg/L	Zn mg/L
1	A	0.0063	0.0104	0.0012	0.1991	<0.0001	<0.0001	0.0223	<0.0001	0.003	0.0001
2	B	0.0001	<0.0001	0.0002	0.2144	<0.0001	<0.0001	0.00123	<0.0001	0.0001	0.00011
3	B	<0.0001	0.0102	0.0025	0.2108	<0.0001	<0.0001	0.0056	<0.0001	0.0001	0.0002
4	B	<0.0001	0.00012	0.0036	0.1769	<0.0001	<0.0001	0.0053	<0.0001	0.0002	0.0001
5	C	<0.0001	0.0003	0.0012	0.2009	<0.0001	<0.0001	0.0261	<0.0001	0.00015	0.0021
6	A	<0.0001	0.0025	0.00012	0.1713	<0.0001	<0.0001	0.0062	<0.0001	0.0002	0.00011
7	C	<0.0001	0.0012	0.0023	0.2015	<0.0001	<0.0001	0.0052	<0.0001	0.0063	0.0021
8	C	<0.0001	0.003	0.0023	0.104	<0.0001	<0.0001	0.0065	<0.0001	0.0006	0.0014
9	B	<0.0001	0.0122	0.0063	0.1203	<0.0001	<0.0001	0.0032	0.0012	0.0008	0.0009
10	B	<0.0001	0.0036	0.00023	0.1717	<0.0001	<0.0001	0.0078	0.0069	0.0002	0.0001
11	C	<0.0001	0.00056	0.0053	0.0156	<0.0001	<0.0001	0.0032	<0.00001	0.00075	0.0011
12	B	<0.0001	0.0006	0.00012	0.0325	<0.0001	<0.0001	0.0045	<0.0001	0.0091	0.0011
13	C	<0.0001	0.0012	0.00012	0.0144	<0.0001	<0.0001	0.0032	<0.0001	0.00013	0.0023
14	A	0.0002	0.00048	0.00063	0.0012	<0.0001	<0.0001	0.0058	<0.0001	0.0089	0.009
15	D	<0.0001	<0.0001	0.00012	0.0325	<0.0001	<0.0001	0.0021	<0.0001	0.00089	0.0002
Mean		**0.0022**	**0.003863**	**0.001749**	**0.124473**			**0.007215**	**0.00405**	**0.002095**	**0.001395**
Median		**0.0002**	**0.0012**	**0.0012**	**0.1713**			**0.0053**	**0.00405**	**0.0006**	**0.0009**

Key:

A = Shallow well | **B** = Borehole | **C** = Open well | **D** = Tap water

73.4% of the total samples examined showed acceptable levels of copper and arsenic, largely in rural groundwater. With a median of 0.17 and the highest test findings of 0.2144mg/l from a groundwater borehole at site 2, which is a few kilometres from the KCM open pit, only nickel was over permissible limits in all water sources.

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Analyses the median concentrations of heavy metals from various sources during the dry and wet seasons according to various requirements for drinking water. Arsenic concentrations in tap water, open wells, and boreholes during the wet season were below detectable limits and within levels permitted for drinking water for all standards, yet the health risks cannot be neglected, especially since water is used daily. Nickel median concentrations throughout the dry season and from all sources were higher than allowed by the US EPA and WHO. According to data from WHO, ZABS, and the US EPA, the median concentrations of lead in rural and urban groundwater sources during the dry and wet seasons were below detectable levels. According to data from the USEPA and ZABS, the median copper contents in urban and rural groundwater sources during both the dry and rainy seasons were within allowable ranges.

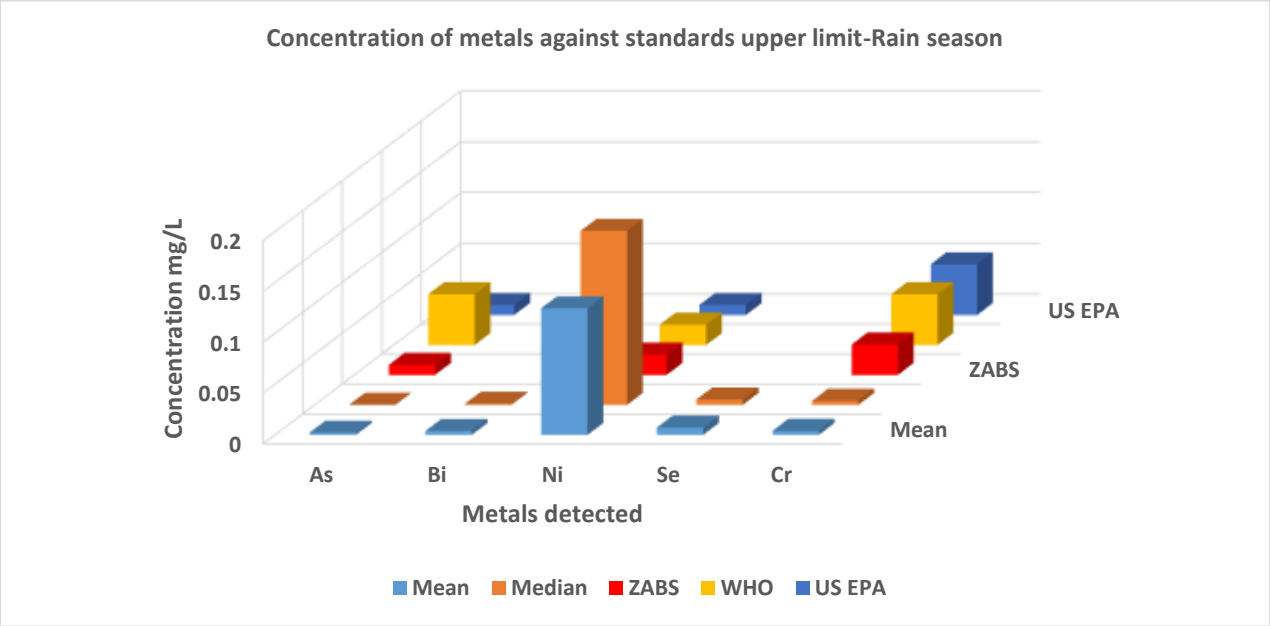

Fig. 3: Showing the mean and median concentrations of metals detected at the ZABS, WHO, and US EPA upper limits.

The data shows that most metals were below the upper limit on a single intake base in most sources of drinking water, except for those that showed a mean and median that were higher than the levels recommended. But in most sources, it remained consistently higher than the upper threshold of the regulatory bodies. It was also found that individual sources of water for arsenic still showed significantly high levels, such as sites 1 and 14. This was true for all the seasons.

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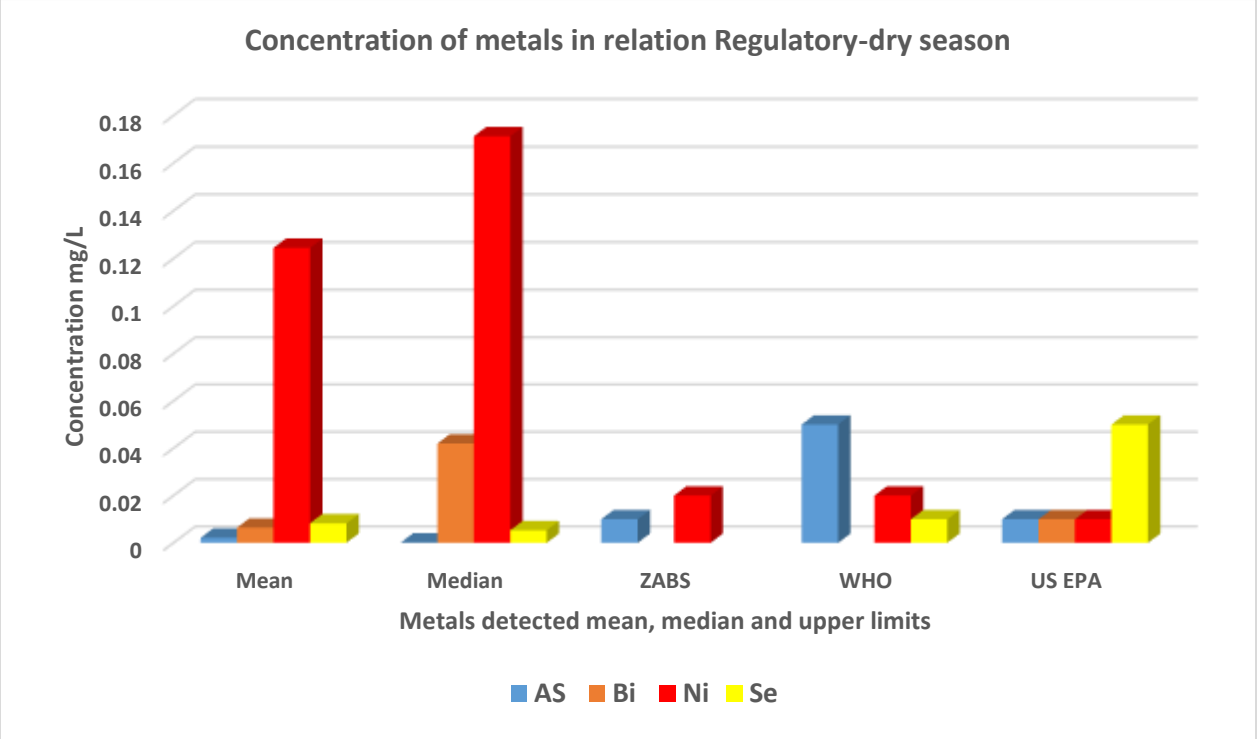

Fig 3: Showing the mean and median concentrations of metals detected about ZABS, WHO and US EPA upper limits.

Health risks analysis.

Health risk analysis can be divided into two categories: non-carcinogenic and carcinogenic. In this study, the term non-carcinogenic refers to metals that are not known to cause cancer on their own. These metals include Ni, Bi, and Se. While carcinogenic metals may include As, Cr, and bismuth (Bi), due to infrequent occurrences in water in various parts of the world, relatively few regulatory bodies have set limitations. In our instance, it may be important to analyse the water index level. According to the US EPA (2004) and Mohammad *et al* (2019), the risks can be assessed on two fronts. Chronic daily intake (CDI) oral is the ingesting of heavy metals. The other possibility is chronic daily intake (CDI) dermal, which is metal exposure through the skin.

$$(CDI)_{oral}(mgKg^{-1}day^{-1}) = \frac{C_{hm} \times DI \times ABS \times EF \times ED}{BW \times AT}$$ Eqn 1, US EPA 2004 and Mohammad et al 2019

$$(CDI)_{dermal}(mgKg^{-1}day^{-1}) = \frac{C_{hm} \times SA \times K_p \times ABS \times ET \times EF \times ED \times CF}{BW \times AT}$$ Eqn 2, US EPA 2004 and Mohammad et al 2019

Where table 1.3 below shows the meaning of each parameter and some constants that need to be used in the calculation.

Parameter	unit	Values		References
		Ingestion	Dermal absorption	
Heavy metals concentration (**C_{hm}**)	mg/L	-	-	from raw data
Daily Average Intake (**DI**)	L/Day	2.2	-	Mohammad et 2019
Skin surface Area (**SA**)	cm^2	-	18000	US EPA 2004
Permeability Coefficient **K_p**		-	Cd, Cr, Fe, Mn & CU = 0.001; Pb = 0.0001 and Zn = 0.0006	US EPA 2005
Time of exposure (**ET**)	Hour/event	-	0.58	US EPA 2004
Exposure frequency (**EF**)	Days/Year	365	350	US EPA 2005
Exposure duration (**ED**)	Year	71.8*	30	US EPA 2004
Conversion factor (**CF**)	L/cm^3	-	0.001	US EPA 2004
Average Body Weight (**BW**)	kg	60*	60*	Mohammad et al 2019
Absorption Factor (**ABS**)	-	0.001	0.001	US EPA 2004; Mohammad et 2019
Average time (**AT**)	Days/Year	26297	10500	-

*mean for females and males

The CDI oral or dermal, become even more useful when compared to the oral reference dose (R_fD) for a particular heavy metal. This ratio is called Hazard Quotient (HQ) oral or HQ dermal. The HQ oral or dermal can be calculated as:

$$HQ_{oral} = \frac{CDI_{oral}}{R_fD} \qquad \text{Eqn 3}$$

$$HQ_{oral} = \frac{CDI_{dermal}}{R_fD} \qquad \text{Eqn 4}$$

Therefore using the summation of the various HQ oral or dermal, the potential non-carcinogenic or carcinogenic Hazard Index (HI) can be calculated, Zakir et al (2020) Mohammad et al (2019) and the US EPA (2005), states that the values of the HI can be used to determine risks. If HI is greater than 1.0, from the sum HQ of all the metals detected, then the exposed population is at a non-carcinogenic risk from the metal. These are other effects those specific metals cited may cause in the lives of the exposed population.

The HI can be calculated as in equations 5 and 6 below.

$$HI_{oral} = \sum_i^n HQ_{metal\,1} + HQ_{metal\,2} + HQ_{metal\,3} + HQ_{metal\,ni} \qquad \text{Eqn 5 Zakir et al 2020}$$

$$HI_{dermal} = \sum_i^n HQ_{metal\,1} + HQ_{metal\,2} + HQ_{metal\,3} + HQ_{metal\,ni} \qquad \text{Eqn 6 Zakir et al 2020}$$

The data in the table below shows the CDI, HQ and R_fD

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Table 1.4 shows the daily dose references for oral, dermal and inhalation and the cancer slope factors US EAP 2005, Aghavi *et al* 2023.

Heavy metals	(mg/kg/day)									µg/kg/day
	Pb	**Co**	**Cr**	**Ni**	**Cu**	**As**	**Zn**	**Se**	**Bi**	**Te**
RfD Ingestion	3.5×10^{-3}	0.005	3.0×10^{-3}	2.0×10^{-2}	4.0×10^{-2}	2.71×10^{-4}	3.0×10^{-1}	5.0×10^{-3}	15*	210**
RfD Dermal	5.3×10^{-4}	0.005	3.0×10^{-3}	2.0×10^{-2}	4.0×10^{-2}	2.71×10^{-4}	3.0×10^{-1}	5.0×10^{-3}	-	-
RfD Inhalation	3.5×10^{-3}	0.005	3.0×10^{-5}	2.5×10^{-2}	4.5×10^{-2}	3.0×10^{-3}	3.5×10^{-1}	5.7×10^{-4}	-	-
CSF Ingestion	8.50×10^{1}	-	5.0×10^{-1}	1.7×10^{0}	-	1.5×10^{0}	-	-	-	-
CSF Dermal			2.0×10^{1}	4.2×10^{2}	-	1.5×10^{0}				

* Poddalgoda et al 2020

** Filipini et al 2020.

Then therefore the calculations of CDI, HQ and HI can be understood as below:

For AS $(CDI)_{oral}(mgKg^{-1}day^{-1}) = \frac{C_{hm} \times DI \times ABS \times EF \times ED}{BW \times AT} = \frac{0.0022 \times 2.2 \times 0.001 \times 360 \times 72}{60 \times 26297} = \frac{0.1254528}{1,577,820}$

$= \mathbf{8.0 \times 10^{-8}\, mgKg^{-1}day^{-1}}$

Meanwhile, Hazard quotient (HQ) = $\frac{CDI}{R_fD} = \frac{8 \times 10^{-8}}{2.71 \times 10^{-3}} = \mathbf{0.0003}$

The other data were worked as above and the following data was found for both the dry and wet season. The mean concentration, as well as the median, were both tried to check for non-carcinogenic and carcinogenic health risks.

Table 1.5 Showing health risk analysis parameters (CDI oral, HQ and HI) for the sampled sources of water for the Wet season.

	Wet season concentration Based on mean and median										
	AS mg/L	**Bi mg/L**	**Co mg/L**	**Ni mg/L**	**Pb mg/L**	**Sb mg/L**	**Se mg/L**	**Te mg/L**	**Cu mg/L**	**Zn mg/L**	**HI**
Mean C_{hm}	**0.0022**	**0.006423**	**0.002648**	**0.124473**	**bdl**	**bdl**	**0.008293**	**0.00405**	**0.006667**	**0.000855**	
CDI	8.1E-08	2.35E-07	9.7E-08	4.56E-06			3.04E-07	1.48E-07	2.44E-07	3.13E-08	
HQ	0.0003	1.57E-08	4.71E-05	0.002281			6.08E-05	0.000645	6.11E-06	1.04E-07	**0.003337**
Median C_{hm}	**0.0002**	**0.0042**	**0.003**	**0.1713**	**bdl**	**bdl**	**0.0068**	**0.0006**	**0.0025**	**0.0009**	
CDI	7.33E-09	1.54E-07	1.1E-07	6.28E-06			2.49E-07	2.2E-08	9.16E-08	3.3E-08	
HQ	2.09E-06	1.03E-08	2.2E-05	0.000314			4.98E-05	0.000105	2.29E-06	1.1E-07	**0.000495**

Table 1.6 Shows health risk analysis parameters for the sampled water for the Dry season.

	Dry Season concentration based on mean and median										
	AS mg/L	**Bi mg/L**	**Co mg/L**	**Ni mg/L**	**Pb mg/L**	**Sb mg/L**	**Se mg/L**	**Cr mg/L**	**Cu mg/L**	**Zn mg/L**	**HI**
Mean	**0.0022**	**0.003863**	**0.001749**	**0.124473**	**bdl**	**bdl**	**0.007215**	**0.00405**	**0.002095**	**0.001395**	
CDI	8.06E-08	1.46E-07	6.40E-08	4.56E-06			2.64E-07	1.48E-07	7.67E-08	5.11E-08	
HQ	2.98E-05	9.44E-09	1.28E-05	0.0002281			5.29E-05	4.95E-05	1.92E-06	1.70E-07	**0.000375**
Mean	**0.0002**	**0.0012**	**0.0012**	**0.1713**	**bdl**	**bdl**	**0.0053**	**0.00405**	**0.0006**	**0.0009**	
CDI	7.33E-09	4.4E-08	4.4E-08	6.28E-06			1.94E-07	1.48E-07	2.2E-08	3.3E-08	
HQ	2.09E-06	2.93E-09	8.79E-06	0.000314			3.88E-05	4.95E-05	5.5E-07	1.1E-07	**0.000414**

bdl =below detection limit

The carcinogenic health risk analysis.

The carcinogenic hazard index (HI) is the summation of Hazard quotients HQ of carcinogenic metals, such as Arsenic, lead and chromium. Mathematically it can be as:

$$HI_{carcinogenic} = \sum_i^n HQ_{As} + HQ_{pb} + HQ_{Cr}$$ Eqn 7 Zakie et al 2020, Muhmmadi et al 2019

With lead (Pb) being below instrument limits < 0.001 therefore below the detection limit (bdl) therefore assigned zero HQ.

Hence $HI_{carcinogenic}$ = 0.0003 + 0 + 4.95E-05 = **0.000345**

It was noted that either by using the median or the mean values of various metal concentrations, the Health risk index (HI) was still below the threshold of 1.0. This is a good sign even in cases of higher than allowed upper limits. In mining towns, it is not strange to find elevated concentrations

of metals, just as Daka and Kamanga (2023) highlighted a high concentration of metals in rivers just in the nearby town of Chingola district. They attributed the increase to mining activities.

There were some significant differences in the values of HI for the rainy season and the dry season. HI (wet) equals **0.003337**. HI (dry) equals **0.000375**. This could be attributed to surface run-offs that may transport and lead to the leaching of some metals between contamination points and sources of water. This was consistent with what Daka and Kamanga did. (2023) found leaching of metals from point-source pollution to the water source in Mufulira. It was generally observed that the concentration of various materials in sources was higher in the wet season than in the dry. As for the median HI, there was not much of a difference, as in some metals the median was still relatively much lower than the mean for the metal.

The incremental lifetime cancer risk assessment (ILCR and CR)

To ascertain whether exposure to such sources of water for a lifetime by an individual is possible, equations 8 and 9 were used. The equation is based on EPA 2004, which states:

$$Cancer\ Risk\ (CR) = CDI \times CSF$$ Equation 8. USEPA 2004.

Incremental Lifetime cancer risk = $\sum_{i=1}^{n} CDI_i \times CSF_i$ Equation 9. USEPA 2004

Where CDIi is an individual's chronic daily intake and CSF is the cancer slope factor (mg/Kg/day)-1. Using the CSF in Table 1.4 above According to the US EPA (2004), excess cancer risks that are below 1 chance in 1,000,000 (1×10^{-6}) are considered small and negligible, while the risks above 1 in 10,000 (1×10^{-4}) are considered to be large, and some remediation is desirable (EPA 2004; Aliyu et al., 2022.

Cancer Risk (CR) (Wet session) = 8.1 x 10^{-8} x 1.5 = **1.21 x 10^{-7}**.

The CR assessment can be understood in Table 1.7 below.

Table 1.7 shows the CR for sessions and the ILCR for each metal.

Metals	As	Ni	Cr
CR WET	1.21 x 10^{-7}	7.75 x 10^{-6}	7.40 x 10^{-8}
CR DRY	1.22 x 10^{-7}	1.07 x 10^{-5}	7.40 x 10^{-8}
ILCR (all year)	2.42 x10^{-7}	1.84 x 10^{-5}	1.48 x 10^{-7}
Overall ILCR	**1.88 x 10^{-5}**		

The ILCR for all metals found at a particular water source would be 1.88 x 10^{-5}. Which is greater than 10^{-6} but less than 10^{-4}. The value found is in between the lower limit and the upper limit. This

may mean that there may be a significant health risk that could cause cancer, but it falls below remediation alert levels. However, with the Copperbelt Province being a heavy mining region, it may be necessary to put remedial measures in place even when exploiting the richness of minerals. This, too, implies that the exploration of minerals should be conscious of the risks and long-term remedial means.

Comparisons between seasons and different locations of water sources

The Kruskal-Wallis one-way analysis of variance test was used to compare heavy metal levels as reported by various sources. The three sources were tap water, groundwater in rural areas, and groundwater in populated areas.

Table 1.8 Kruskal–Wallis comparison of heavy metals between Tap water, Borehole, open well and shallow well

Heavy Metal	P-Value
Arsenic	0.5
Cobalt	0.3
Nickel	0.5
Lead	0.5
Copper	0.3
Zinc	0.3
Chromium	0.1

According to Table 1.8, there were statistically significant differences in the median amounts of cobalt, copper and zinc in drinking water from rural and urban groundwater sources ($p > 0.05$).

Table 1.9 Comparing seasonal variations of heavy metals Seasonal variation of heavy metal was done using a Two-sample Wilcoxon rank-sum

Heavy Metal	P-Value
Arsenic	0.4
Cobalt	0.4
Nickel	0.6
Lead	0.5
Copper	0.3
Zinc	0.4
Chromium	0.1

According to Table 1.9, there was a statistically significant difference in the median concentrations of cobalt, copper and zinc throughout the dry and wet seasons ($p < 0.05$). This may be related to the difference in the levels of Konkola Copper Mines' mining operations (KCM)

Nickel

In the dry season, nickel levels in all water sources were higher than those allowed by the WHO. While shallow well water sources had a median concentration of 0.1743 mg/L throughout both wet and dry seasons, boreholes' water had the greatest average from the triplicate samples concentration of 0.214 mg/L during both wet and dry seasons. In Zambia, nothing is known about the concentrations of nickel in water sources. The majority of the available data comes from research that primarily employed soil and river samples. The researcher analyzed all papers on Zambia, but none of them mentioned any appreciable levels of nickel in the water. Studies conducted in other environments, however, have found higher nickel levels in sources of drinking water Itodo *et al* (2011) observed high nickel concentrations in bore-hole water from Kebbi state, Nigeria, among other heavy metals. Nickel is a common element of the Earth's surface, present in all environmental compartments and pervasive in the biosphere. One of the principal natural sources of nickel, according to Duda-Chodak and Blaszczyk (2008), is weathering of rocks and soils.

Other heavy metals

The remaining heavy metals' median amounts were below the limits that were considered acceptable. Copper, cobalt, and zinc acceptable levels were provided by sampling stations. Antinomy and lead concentrations were undetectable. Limits According to research by Ndilila *et al* (2014), in Zambia, locations far from mining sites have much lower concentrations of cobalt, copper, lead, and zinc in toenails than those close to mining areas. According to Sracek *et al* (2012), mining operations along the Kafue River in the Chingola area are to blame for the higher

cobalt and copper levels. Ikenaka *et al* (2010) also discovered that there were only moderate or low amounts of heavy metals in places that were geographically far from mining beds. Mining operations were named as the primary cause of water contamination by Blacksmith Institute in 2006. In several sample areas, higher levels of copper and cobalt are probably related to mining activity.

In the research area's water sources throughout both the wet and dry seasons, cadmium and chromium concentrations were all below the detection threshold. This suggests that either there were no traces of the metal ions listed in the research region or that their concentrations were just too low for the analytical device to pick them up. Considering that cadmium and chromium may pose a concern (UNICEF 2008; World Health Organization), this is encouraging (WHO, 2010). Chromium levels in natural water are typically low, but mining and industrial operations can lead to higher levels (Momodu and Anyakora 2010The lack of industrial activities involving chromium and cadmium in its operations is indicated and presumably confirmed by the non-detect result for chromium in this investigation.

Heavy metal variations due to season and various sources

In this investigation, there was a significant difference between the four drinking water sources in terms of arsenic, copper, and manganese ($P > 0.05$). Between the dry and rainy seasons, there were considerable differences in arsenic, nickel, manganese, and cobalt levels. Significant ($p > 0.05$) heavy metal fluctuation was found in several water samples from Irbid City, Northern Jordan, according to research by Alomary *et al* (2013). According to location/source, the season of the year, and heavy metal content, Malassa *et al* (2013) found a substantial variation. This demonstrates how the median heavy metal concentrations from distinct samples are affected differentially by different sampling sites. This indicates that anthropogenic contamination with heavy metals is probable. This outcome may be explained by the fact that such heavy metals that originate from anthropogenic sources are gathered and concentrated during dry months, then washed with the first raindrops of rainfall and leached to the groundwater at the commencement of rainfall Malassa *et al* (2013). Changes in the groundwater flow route and minor alterations in the pH-dependent processes of mineral dissolution and precipitation (hydrogeology) may cause variances in this respect Oyem *et al* (2015) also noted that seasonal changes are the main cause of arsenic variations.

CONCLUSION

The Hazard indices for both dry and wet seasons for all the sources indicate that carcinogenic and non-carcinogenic water sources in the Chingola district are below the Hazard index threshold of 1.0. This range is beyond the levels of all the regulatory bodies. The ILCR for various metals across the sessions stood at 1.88×10^{-5}. This is greater than 10^{-6} and hence may cause lifetime cancer in a person dependent on the water, but less than 10^{-4} may merit remediation. However, it should be kept in mind that mining activities need to be proactive in the remediation of heavy metals; other areas of the land in mining areas may be heavily polluted and highly risky for cancer and non-carcinogenic diseases. The water sources' CRs are within the permissible range. However,

the levels of some metals are significantly higher than the permissible upper limit for daily intake, which translates to a higher value of CR of 1.85 x 10^{-5}, which by itself is significant enough to raise carcinogenic risk concerns. Nickel could be cited, which had values ranging from 0.00012 to 0.2144 mg/L.

In all water samples, the levels of chromium and cadmium were below detection. Lead, arsenic, copper, manganese, iron, and zinc are heavy metals that could have negative effects on health even when on the Hazard Indices (HI) analysis level they may be within permissible limits. In 93% of the sampling locations, the highest nickel levels were noted. The tailings damping sites can also not be ruled out as a possible source of contamination for metals. Meanwhile, when evaluation was done on the concentration of sources of water from 15 km from the mine area to 68 km away, the p-value was greater than 0.005, which showed that there was a difference in the level of heavy metals in water sources that could be attributed to location. One is near the source of pollution, which are mines and their activities.

Acknowledgements

Great gratitude to the Management of Mulungushi University and particularly the faculty staff. Special mention Mr. Banda Danny for taking the time to listen and correct the process of data acquisition. SLT 2023 team we salute your contribution. Lastly but not least the Almighty who dwells in high places.

Conflict of Interests

The authors wish to declare that there are no conflicts of interest that may prevent your Journal to make publication of our work.

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