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Characterization And Human Health Risks Assessment Of Mixed Toxic Metals And Radionuclides In Contaminated Tin Mine Tailings

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Abstract
Tin mining and associated tailings in Plateau State, Nigeria, have led to substantial environmental degradation and human health concerns. Tailings—comprised of both magnetic minerals (e.g., iron ore, columbite) and non-magnetic ones (e.g., cassiterite, monazite, zircon, silica)—often contain elevated levels of naturally occurring radionuclides (e.g., uranium, thorium) and toxic heavy metals (lead, cadmium, arsenic, chromium, mercury). While some tailings are repurposed as fertilizer or construction fill, the bulk remains untreated, posing Human health risks and contaminant exposure to local communities. This study evaluates the concentrations of heavy metals and radionuclides in tailings from four dumpsites—Zawan A, Kuru A, Sharubutu, and Rim—in Jos South and Riyom LGAs. Human health risk assessments were conducted following standard USEPA exposure models, quantifying pathways of ingestion, inhalation, and dermal contact. Risk indicators such as hazard quotients (HQ), hazard indices (HI), and total cancer risk (TCR) were calculated for both children and adults. Results indicate that, while non-carcinogenic risks generally remain below critical thresholds (HI < 1), carcinogenic risks—especially from lead ingestion—are significantly elevated in children at Zawan A and Kuru A, with additional risks observed among adults at Zawan A. Uranium ingestion further contributes to carcinogenic risk across most sites. The ingestion exposure pathway emerged as the primary health concern, followed by inhalation and dermal contact. These findings underscore the urgent need for environmental monitoring, targeted remediation, and public health interventions, particularly for vulnerable populations in mining-adjacent communities. The study advocates for policy reforms aimed at regulating tailings disposal and land use, and recommends further research into long-term human health impacts and sustainable remediation technologies.
***Keywords**: Tin mine tailings, toxic metals, radionuclides, human health risk assessment, USEPA, Nigeria*

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I. Introduction

Tin mining has long been a source of environmental pollution, primarily due to the release of naturally occurring radionuclides and heavy metals into nearby ecosystems. The waste produced during tin ore processing, known as tailings, often contains elevated levels of these toxic substances, posing serious risks to both human health and the environment [1]. These tailings may consist of magnetic minerals like iron ore and columbite, as well as non-magnetic ones such as cassiterite, monazite, zircon, and silica. Despite their potential value, such materials are often discarded without further utilization [2]. However, in some cases, they are repurposed for applications in fertilizers, animal feed, refractory products, road construction, and site backfilling [3].

Although Nigeria was a major tin producer in the 1960s, mining operations continue today, contributing to the accumulation of vast quantities of waste. For example, tailings can constitute 90–98% of the material in copper mining and 20–50% in the extraction of other ores [4]. These residues frequently contain radionuclides such as uranium and thorium, which emit ionizing radiation associated with cancer and genetic disorders [5]. Moreover, heavy metals like lead, cadmium, arsenic, and mercury can enter the food chain through bioaccumulation, leading to long-term health problems such as neurological damage, kidney failure, and developmental impairments [6]. The formation of large tailing ponds further worsens environmental degradation, significantly affecting nearby ecosystems and human settlements.

To accurately evaluate the health risks posed by tin mine tailings, it is crucial to assess the concentration of heavy metals at these sites and their potential effects on human populations. This requires preliminary studies that analyze the properties of the waste materials, the levels of toxic metals, and their interactions with the environment—especially concerning miners and nearby communities [7].

Human health risk assessments aim to evaluate the potential health effects resulting from exposure to environmental contaminants [8]. These effects depend on the exposure level, the type of contaminant, and the susceptibility of affected individuals [9]. Possible health consequences include an increased risk of cancer, high blood pressure, fetal neurological disorders, organ damage, respiratory illnesses, mental and physical health issues, reduced life expectancy, and weakened immune function [8].

Therefore, this study seeks to assess both ecological and human health risks associated with toxic metals present in tin mine tailings from the communities of Zawan A (ZS1), Kuru A (KS2), Sharubutu (SS3), and Rim (RS4), located in Jos South and Riyom Local Government Areas of Plateau State, Nigeria.

II. Research Methodology

Sample location and site description

Tailings and farmland soils were sampled from Zawan A, Kuru A, Sharubutu, and Rim all in Jos south and Riyom Local Government Areas Plateau state, Nigeria. Analytical methods included atomic absorption spectrophotometry and gamma photometry. Ecological risk indices were calculated using the measured contaminant concentrations alongside reference data.

Plateau state is located in the middle belt of Nigeria's with an area of 30.91 km (11936 sq mi), the state has an estimated population of about three million people. It is located between latitude 9051'30"N to 1002'00"N and longitude 8048'00"E to 9051'00E. The name Plateau state emerged due to its mountainous topography with captivating rock formations. The mountains attitude ranges from around 1,200 meter (about 400 feet) to a peak of 1,829 meters above sea. The predominant occupation of the people here is mining and subsistence farming, 500 g of each of the sample was taken.

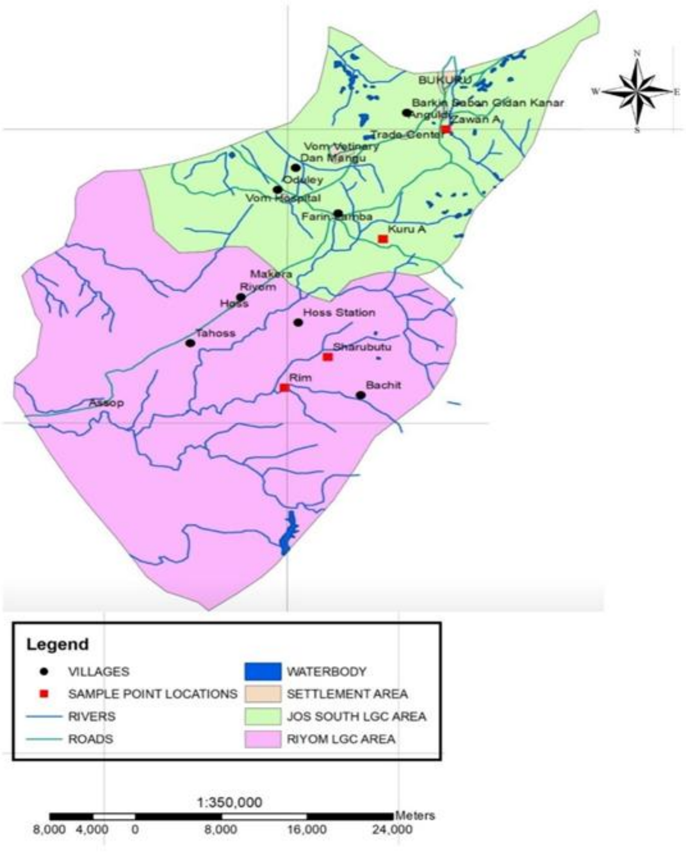

Figure 1: Map Showing the Location of the Study Area
Source: Cartographic, GIS and Remote Sensing Studio Department of Geology University of Jos, 2023.

Figure 1 showed the sampling points where the tailing samples were taken from in Jos South and Riyom L.G.A. of Plateau State. The Geographical Positioning System (GPS) was used to locate the sampling area to ensure consistency. Each sample was taken from the mining site in Zawan A (ZS1) and Kuru A (KS2) of

Jos-South Local Government Area, Sharubutu (SS3) and Rim (RS4) of Riyom Local Government Area of Plateau State, Nigeria.

Sample preparation

Four samples of 500 g each were taken from the mining and the control sites respectively. The Tin mine tailing and soil samples was pretreated through washing, drying and in some cases grinding to size particles of 2 mm to distinguish between small large particles. The goal of pretreatment procedure was to prepare a test sample in which the concentration in the original soil provided however, this procedure did not alter chemical specie analyzed.

III. Results And Discussions

Human Health Risk Assessment

Human health risk assessment (HHRA) is a systematic approach used to evaluate the potential harmful effects on human health from exposure to environmental hazards, chemicals, or other risk factors [22]. The presence of toxic metals (TMs) and radionuclides (R) in the soil poses a silent threat to human health through various exposure pathways, such as skin contact, ingestion, and inhalation [23]. Several studies have identified factors that influence the toxicity of exposure to these contaminants, including the exposure pathway, absorption, metabolism, and distribution within the human body [10]. Additionally, age is a critical factor that warrants careful consideration. Infants and children are more vulnerable to the effects of contaminants compared to adults, due to their behavioral traits, such as playing in dust, mouthing non-food objects, and sucking their hands or fingers. These behaviors increase the likelihood of exposure to soil contaminants [10]. Tables 1 to 5 present data on both non-carcinogenic and carcinogenic exposures at different dumpsites in Jos, Nigeria.

Human Health Risk Assessment Parameters

The carcinogenic and non-carcinogenic risks were evaluated using the human health risk assessment model for dermal contact, ingestion and inhalation exposure pathways [9]. The health risk assessment is centered on the exposure factors and guidelines handbook of United States Environmental Protection Agency (USEPA) [11]. The average daily dose (ADD) via inhalation (ADD_{inh}), ingestion (ADD_{ing}) and dermal contact (ADD_{derm}) for both children and adults were evaluated using equations (1)-(3) as adopted from [9].

Ingestion dose $D_{ing\text{-}g} = \frac{Cs\ X\ IngR\ X\ EF\ X\ ED\ X\ CF}{BW\ X\ AT}$ (1)

Inhalation dose $(D_{inh\text{-}s}) = \frac{Cs\ X\ InhR\ X\ EF\ X\ ED}{BW\ X\ AT\ X\ PEF}$ (2)

Dermal dose $(D_{der\text{-}s}) = \frac{Cs\ X\ SA\ X\ SL\ X\ EF\ X\ ED\ X\ CF}{BW\ X\ AT}$ (3)

Where C_s is the concentration of the analyte in the tailing from exposure point (mg/kg), IngR – tailing ingestion rate for the receptor (mg/d), InhR – soil inhalation rate for the receptor (m3/d), EF – exposure frequency (days/year), ED – exposure duration (years), PEF – soil-to-air particulate emission factor (m^3/kg), SA – skin surface area available for exposure (cm^2), SL- soil-to-skin adherence factor (mg/cm^2/event), BW – time-averaged body weight (kg), AT – average time of non-carcinogenic and carcinogenic risks (days) and ABS – dermal absorption factor(dimensionless). The hazard quotient, hazard index and total cancer risk were evaluated using equations (4) – (6) as adopted from Man [21].

The Hazard Quotient is given as:

$HQ = \frac{D}{RfD}$ (4)

Where D = Dose (ingestion, inhalation or dermal), RfD = reference dose. The hazard index HI is given as:

$HI = HQ_{ing} + HQ_{inh} + HQ_{derms}$ (5)

Total cancer risk (RT) is given as:

RT = D x SF (6)

Where D = Dose, SF = Slope factor

Risk characterization was considered separately for carcinogenic and non-carcinogenic effects [19]. Health risks were obtained by comparing the calculated HQ, HI and R_{total} values with recommended maximum values shown on table 1

Table 1: Hazard Quotients and Cancer Risks of Contaminants in ZawanA Mine Tailing Dump site around Jos, Nigeria.

Entry route	Contaminant	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
	Cd			8.43×10^{-1}	4.30×10^{2}
	Pd	1.95×10^{-1}	1.11×10^{-3}	2.31×10^{0}	1.32×10^{-2}

Ingestion	Cr	1.73×10^{-3}	8.82×10^{-5}	5.82×10^{0}	1.32×10^{-1}
	U			3.53×10^{0}	2.92×10^{0}
	Th			5.22×10^{-1}	2.65×10^{-2}
	K			BDL	BDL
	Cd			2.02×10^{-1}	1.06×10^{-3}
	Pd	3.65×10^{-4}	6.95×10^{-5}	1.09×10^{-1}	2.07×10^{-3}
Inhalation	Cr	7.03×10^{0}	1.20×10^{-6}	1.605×10^{-1}	1.7×10^{-1}
	U			2.72×10^{-1}	2.73×10^{-1}
	Th			1.46×10^{-2}	2.52×10^{-3}
	K			BDL	BDL
	Cd			9.71×10^{-2}	6.5×10^{-3}
	Pd	5.98×10^{-7}	4.42×10^{-9}	2.67×10^{-3}	1.97×10^{-5}
Dermal	Cr	9.91×10^{-9}	3.833×10^{-11}	6.59×10^{-2}	1.115×10^{-4}
	U			4.20×10^{-2}	4.23×10^{-2}
	Th			5.97×10^{-4}	3.95×10^{-5}
	K			BDL	BDL

BDL: Below Detection Limit

Table 2: Hazard Quotients and Cancer Risks of Contaminants in Kuru A Mine Tailing Dump site around Jos, Nigeria.

Entry route	Contaminant	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
	Cd			2.74×10^{1}	1.395×10^{0}
	Pd	2.87×10^{1}	1.45×10^{-2}	3.41×10^{2}	1.75×10^{-1}
Ingestion	Cr	1.7×10^{0}	5.44×10^{-5}	1.600×10^{-3}	8.17×10^{-2}
	U			6.04×10^{0}	3.08×10^{-1}
	Th			5.19×10^{-10}	4.4×10^{-1}
	K				
	Cd			3.40×10^{-3}	5.906×10^{-6}
	Pd	4.44×10^{-1}	7.59×10^{-4}	1.33×10^{1}	2.30×10^{-2}
Inhalation	Cr	1.632×10^{-5}	1.057×10^{-6}	2.34×10^{0}	1.20×10^{-1}
	U			1.69×10^{-1}	3.55×10^{-2}
	Th			1.455×10^{-2}	4.13×10^{-1}
	K			BDL	BDL
	Cd			3.15×10^{-2}	2.10×10^{-3}
	Pd	8.90×10^{0}	5.87×10^{-8}	3.93×10^{-1}	2.60×10^{-3}
Dermal	Cr	6.133×10^{-9}	4.083×10^{-9}	1.84×10^{-3}	1.23×10^{0}
	U			6.90×10^{-3}	4.64×10^{0}
	Th			5.50×10^{-4}	6.60×10^{-4}
	K			BDL	BDL

BDL: Below Detection Limit

Table 3: Hazard Quotients and Cancer Risks of Contaminants in Sharubutu Mine Tailing Dump site around Jos, Nigeria.

Entry route	Contaminant	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
	Cd			8.42×10^{1}	6.31×10^{-2}
	Pd	3.02×10^{-2}	1.52×10^{-3}	3.50×10^{0}	2.61×10^{0}
Ingestion	Cr	1.27×10^{-3}	6.49×10^{-5}	1.905×10^{0}	1.85×10^{-2}
	U			9.12×10^{0}	4.65×10^{-2}
	Th			1.270×10^{0}	6.48×10^{-2}
	K			BDL	BDL
	Cd			1.009×10^{-1}	4.8×10^{-4}
	Pd	1.207×10^{-1}	3.48×10^{-4}	2.06×10^{-1}	1.04×10^{-2}
Inhalation	Cr	3.37×10^{-3}	5.78×10^{-7}	4.83×10^{2}	8.26×10^{-2}
	U			2.55×10^{-1}	4.35×10^{-2}
	Th			3.72×10^{-2}	6.10×10^{-3}
	K			BDL	BDL
	Cd			7.91×10^{-2}	5.31×10^{0}
	Pd	4.26×10^{-3}	8.299×10^{-6}	1.049×10^{-2}	3.70×10^{-2}
Dermal	Cr	7.32×10^{-9}	6.63×10^{-7}	2.20×10^{-3}	1.98×10^{-1}
	U			1.048×0^{-2}	9.50×10^{-1}

	Th			1.46×10^{-3}	1.32×10^{-1}
	K			BDL	BDL

Table 4: Hazard Quotients and Cancer Risks of Contaminants in Rim Mine Tailing Dump site around Jos, Nigeria.

Entry route	Contaminant	$HQ_{Children}$	HQ_{Adult}	$CR_{Children}$	CR_{Adult}
	Cd			1.44×10^{-1}	7.35×10^{1}
	Pd	1.48×10^{-2}	7.54×10^{-4}	1.76×10^{-1}	4.0×10^{-2}
Ingestion	Cr	5.24×10^{-4}	2.66×10^{-5}	7.9×10^{-1}	5.38×10^{-1}
	U			2.30×10^{-1}	5.60×10^{-2}
	Th			2.20×10^{-1}	1.13×10^{-2}
	Cd			7.90×10^{-2}	1.35×10^{-3}
	Pd	1.01×10^{-3}	1.72×10^{-4}	3.01×10^{-2}	3.0×10^{-2}
Inhalation	Cr	1.31×10^{-4}	2.09×10^{-4}	1.87×10^{-1}	3.03×10^{-1}
	U			2.07×10^{-1}	5.3×10^{-3}
	Th			6.19×10^{-3}	1.05×10^{-4}
	Cd			1.66×10^{-1}	1.103×10^{-1}
	Pd	1.58×10^{-2}	7.72×10^{-3}	2.04×10^{-3}	5×10^{-5}
Dermal	Cr	4.8×10^{-9}	1.67×10^{-10}	1.44×10^{-3}	3.31×10^{0}
	U			2.3×10^{-1}	8.40×10^{-4}
	Th			2.54×10^{-4}	1.04×10^{-3}

Table 5: Human Health Risk Assessment of Carcinogenic Hazards of Toxic Metals Corresponding to Different Exposure Pathways.

Land Use	Contaminant	$HI_{Children}$	HI_{Adult}	$TCR_{Children}$	TCR_{Adult}
	Cd			8.56×10^{1}	2.31×10^{-3}
	Pd	1.95×10^{-1}	1.18×10^{-5}	2.43×10^{0}	1.99×10^{-7}
Zawan A	Cr	7.03×10^{0}	8.92×10^{-5}	3.12×10^{-1}	3.05×10^{-1}
	U			5.89×10^{0}	3.23×10^{0}
	Th			5.46×10^{-1}	3.98×10^{-7}
	K				
	Cd			2.75×10^{1}	1.4×10^{0}
	Pd	3.81×10^{-1}	1.52×10^{-2}	3.55×10^{2}	4.25×10^{-2}
Kuru A	Cr	1.07×10^{0}	5.55×10^{-5}	1.602×10^{3}	2.018×10^{-1}
	U			6.22×10^{0}	4.9×10^{0}
	Th			5.34×10^{-1}	4.58×10^{-1}
	K				
	Cd			8.5×10^{1}	7.91×10^{0}
	Pd	3.54×10^{-2}	1.87×10^{-3}	3.50×10^{1}	6.9×10^{-2}
Sharubutu	Cr	4.64×10^{-3}	6.620×10^{-5}	4.84×10^{2}	3.6×10^{-1}
	U			9.38×10^{0}	1.45×10^{0}
	Th			1.30×10^{0}	
	K				2.03×10^{-1}
	Cd			3.2×10^{-1}	7.36×10^{0}
	Pd	1.58×10^{-2}	7.72×10^{-3}	2.68×10^{-1}	5.07×10^{-5}
Rim	Cr	6.54×10^{-4}	1.667×10^{-10}	8.95×10^{-1}	4.14×10^{0}
	U			2.5×10^{-1}	6.2×10^{-2}
	Th			2.3×10^{-1}	1.24×10^{-2}
	K				

Hazard quotient and cancer risks

The hazard quotient (HQ) is the ratio between potential exposure to contaminants and the level at which no adverse health effects are expected. If HQ > 1, adverse health effects are possible; if HQ < 1, no adverse health effects are expected. Table 1 presents the hazard quotients (HQ) for children and adults (CR children; CR adults) around the Zawan A area. The results indicate that ingestion hazard quotients for Cd, Pb, Cr, U, Th, and K for children were 8.43×10^{-1}, 2.3×10^{0}, 5.8×10^{0}, 3.5×10^{0}, 5.2×10^{-1}, and 1, respectively. For adults, the values were 4.30×10^{2}, 2.92×10^{0}, 1.32×10^{-1}, and 1.32×10^{-1}, respectively, following the order: Cr > U > Pb > Th > Cd and Cd > U > Cr > Pb > Th. Ingestion values for adults were 1.05×10^{-3}, 2.07×10^{-3}, 1.7×10^{-1}, 2.73×10^{-1}, and 2.5×10^{-3} for Cd, Pb, Cr, U, and Th, respectively, increasing in the order: Th > Pb > Cd > U > Cr. No carcinogenicity was observed for K, so slope factors were not provided for K. Inhalation HQ for children were 3.65 x 10^{-4} and 7.03 x 10^{0} for Pb and Cr, respectively, in the order: Pb > Cr. Inhalation cancer risks for children were 2.02 x 10-1, 1.09 x 10^{-1}, 1.605 x 10^{-1}, 2.72 x 10^{-1}, and 1.46 x 10^{-2} for Cd, Pb, Cr, U, and Th, respectively. Dermal HQ for children were 5.988 x 10^{-7} and 9.916 x 10^{-9} for Pb and Cr, respectively. These results suggest no expected non-carcinogenic health effects due to exposure via all three routes.

Table 2 presents the mixed contaminants hazard quotient (HQ) and cancer risks (CR) for children and adults around the Kuru A area. The ingestion hazard quotients for Pb and Cr in children were 2.87 x 10^{1} and 1.7 x 10^{0}, respectively. For adults, the values were 1.45 x 10^{-2} and 5.44 x 10^{-5} for Pb and Cr, respectively. Ingestion cancer risks for children were 2.74 x 10^{1}, 3.41 x 10^2, 1.60 x 10^{3}, 1.600 x 10^{3}, 6.04 x 10^{0}, and 5.19 x 10^{-1} for Cd, Pb, Cr, U, and Th, respectively, while for adults, they were 1.39 x 10^{0}, 1.75 x 10^{-1}, 8.17 x 10^{-2}, 3.08 x 10^{-1}, and 4.4 x 10^{-1} for Cd, Pb, Cr, U, and Th, respectively. No carcinogenicity was found for K, so slope factors were not provided for it. Inhalation HQ for children were 4.44 x 10^{-1} and 1.632 x 10^{-5} for Pb and Cr, respectively. Inhalation HQ for adults were 7.59 x 10^{-4} and 1.057 x 10^{-6} for Pb and Cr.

Inhalation cancer risks for children were 3.40 x 10^{-3}, 1.33 x 10^{1}, 2.34 x 10^{0}, 1.69 x 10^{-1}, and 1.455 x 10^{-2} for Cd, Pb, Cr, U, and Th, respectively, while for adults they were 5.906 x 10^{-6}, 2.30 x 10^{-2}, 1.20 x 10^{-1}, 3.55 x 10^{-2}, and 4.13 x 10^{-1} for Cd, Pb, Cr, U, and Th, respectively. Dermal HQ for children were 8.90 x 10^{0} and 6.133 x 10^{-9} for Pb and Cr, respectively, and for adults, 5.87 x 10^{-8} and 4.083 x 10^{-9}. These results indicate no non-carcinogenic health effects from ingestion, inhalation, or skin contact.

Table 3 Provides data for the hazard quotients (HQ) and cancer risks (CR) for children and adults around the Sharubutu area. Ingestion hazard quotients for children for Pb and Cr were 3.02 x 10^{-2} and 1.27 x 10^{-3}, respectively. For adults, the ingestion values were 1.52 x 10^{-3} and 6.49 x 10^{-5} for Pb and Cr, respectively. Ingestion cancer risks for children were 8.42 x 10^{1}, 3.50 x 10^0, 1.90 x 10^{-5}, 9.12 x 10^{0}, and 1.27 x 10^{0} for Cd, Pb, Cr, U, and Th, respectively. For adults, the ingestion risks were 2.61 x 10^{0}, 1.85 x 10^{-2}, 4.65 x 10^{-2}, and 6.48 x 10^{-2} for Pb, Cr, U, and Th. Inhalation HQ for children were 1.20 x 10^{-1} and 3.37 x 10^{-3} for Pb and Cr, respectively. For adults, the values were 3.48 x 10^{-4} and 5.78 x 10^{-7} for Pb and Cr. Inhalation cancer risks for children were 1.009 x 10^-1, 2.06 x 10^{-1}, 4.83 x 10^{-2}, 2.55 x 10^{-1}, and 3.72 x 10^{-2} for Cd, Pb, Cr, U, and Th, respectively, while for adults they were 4.8 x 10^{-4}, 1.04 x 10^{-2}, 8.26 x 10^{-2}, 4.35 x 10^{-2}, and 6.10 x 10^{-3} for the same contaminants. Dermal HQ for children were 4.26 x 10^{-3} and 7.32 x 10^{-9} for Pb and Cr, respectively. For adults, the values were 8.299 x 10^{-6} and 6.63 x 10^{-7} for Pb and Cr, respectively. Dermal cancer risks for children were 7.91 x 10^{-2}, 1.049 x 10^{-2}, 2.20 x 10^{-3}, 1.048 x 10^{-2}, and 1.46 x 10^{-3}, while for adults, the values were 5.31 x 10^{0}, 3.70 x 10^{-2}, 1.98 x 10^{-1}, 9.50 x 10^{-1}, and 1.32 x 10^{-1}, respectively. These findings suggest no non-carcinogenic health effects due to ingestion, inhalation, or skin contact.

Table 4 Presents the hazard quotients (HQ) and cancer risks (CR) for children and adults around the Rim dumpsite area. Ingestion hazard quotients for children for Pb and Cr were 1.48 x 10^{-2} and 5.24 x 10^{-4}, respectively. For adults, the ingestion values were 7.54 x 10^{-4} and 2.66 x 10^{-5} for Pb and Cr. Ingestion cancer risks for children were 1.44 x 10^{-1}, 1.76 x 10^{-1}, 7.9 x 10^{-1}, 2.30 x 10^{-1}, and 2.20 x 10^{-1} for Cd, Pb, Cr, U, and Th, respectively. For adults, the ingestion cancer risks were 7.35 x 10^{1}, 4.0 x 10^{-2}, 5.38 x 10^{-1}, 5.60 x 10^{-2}, and 1.13 x 10^{-2} for Cd, Pb, Cr, U, and Th. Inhalation HQ for children were 1.01 x 10^{-3} and 1.31 x 10^{-4} for Pb and Cr, respectively. For adults, the values were 1.72 x 10^{-4} and 2.09 x 10^{-4}. Inhalation cancer risks for children were 7.90 x 10^{-2}, 3.01 x 10^{-2}, 1.87 x 10^{-1}, 2.07 x 10^{-1}, and 6.19 x 10^{-3} for Cd, Pb, Cr, U.

Hazard index and total cancer risk

Although the interactions between mixed contaminants may be synergistic, it is assumed that the risks associated with all contaminants are additive [24]. The probability of experiencing long-term health effects increases as the Hazard Index (HI) value rises [20]. Table 5 presents the HI and Total Cancer Risk (TCR) for children and adults across four sampling sites. At Zawan A, the HI for children were 1.95 x 10^{-1} for Pb and 7.03 x 10^{0} for Cr, while the HI for adults were 1.18 x 10^{-5} for Pb and 8.92 x 10^{-5} for Cr. The TCR for children were 8.56 x 10^{1} for Cd, 2.43 x 10^{0} for Pb, 3.12 x 10^{-1} for Cr, 5.89 x 10^{0} for U, and 5.46 x 10^{-1} for Th. For adults, the TCR values were 1.99 x 10^{-7} for Pb, 3.05 x 10^{-1} for Cr, 3.23 x 10^{0} for U, and 3.98 x 10^{-7} for Th.

At Kuru A, the HI for children were 3.81 x 10^{-1} for Pb and 1.07 x 10^{0} for Cr, while the HI for adults were 1.52 x 10^{-2} for Pb and 5.55 x 10^{-5} for Cr. The TCR for children were 2.75 x 10^{1} for Cd, 3.55 x 10^{2} for Pb, 1.602 x 10^{3} for Cr, 6.22 x 10^{0} for U, and 5.34 x 10^{-1} for Th. For adults, the TCR values were 1.4 x 10^{0} for Cd, 4.25 x 10^{-2} for Pb, 2.018 x 10^{-1} for Cr, 4.9 x 10^{0} for U, and 4.58 x 10^{-1} for Th.

At the Sharubutu site, the HI for children were 3.54 x 10^{-2} for Pb and 4.64 x 10^{-3} for Cr, and for adults, the HI were 1.87 x 10^{-3} for Pb and 6.620 x 10^{-5} for Cr. The TCR for children were 8.5 x 10^{1} for Cd, 3.50 x 10^{1} for Pb, 4.84 x 10^{2} for Cr, 9.38 x 10^{0} for U, and 1.30 x 10^{0} for Th. For adults, the TCR values were 7.91 x 10^{0} for Cd, 6.9 x 10^{-2} for Pb, 3.6 x 10^{-1} for Cr, 1.45 x 10^{0} for U, and 2.03 x 10^{-1} for Th.

At the Rim site, the HI for children were 1.58 x 10^{-2} for Pb and 6.54 x 10^{-4} for Cr, while the HI for adults were 7.72 x 10^{-3} for Pb and 1.667 x 10^{-10} for Cr. The TCR for children were 3.2 x 10^{-1} for Cd, 2.68 x 10^{-1}

for Pb, 8.95 x 10^{-1} for Cr, 2.5 x 10^{-1} for U, and 2.3 x 10^{-1} for Th. For adults, the TCR values were 7.36 x 10^{0} for Cd, 5.07 x 10^{-5} for Pb, 4.14 x 10^{0} for Cr, 6.2 x 10^{-2} for U, and 1.24 x 10^{-2} for Th.

These results slightly deviate from the pattern (Cd > Pb > Cr) observed by [20] in their study of a dumpsite. However, the general trend that Cu, Pb, and Cd are more prominent is still apparent. The TCR for children were 1.85 x 10^{-9} for R, 1.45 x 10^{-6} for Cd, 1.59 x 10^{-6} for Pb, and 1.19 x 10^{-4} for Ni, while for adults, the TCR values were 1.98 x 10^{-10} for R, 1.56 x 10^{-7} for Cd, 1.70 x 10^{-7} for Pb, and 1.28 x 10^{-5} for Cr.

The HI values across all sites were less than 1, indicating that the hazard levels are considered low at these locations. Additionally, the TCR for adults due to exposure to Cd and Pb were also low at all sites. For children, the TCR due to exposure to Cd and Pb remained within acceptable limits at all sites, except at Kuru A, where the TCR exceeded the limit. In all cases, the risks followed the order: dermal < inhalation < ingestion. This trend aligns with the findings of the U.S. Environmental Protection Agency (USEPA) in 2011, which conducted a health risk assessment of heavy metals in soils from various regions in the U.S. The results also indicate that children are more vulnerable to contaminations from trace metals (TMs) than adults, which corresponds with the conclusions drawn by [20] in their study of a municipal waste dumpsite.

IV. Conclusion

The findings of this study highlight the presence human health risks associated with toxic metal and radionuclide contamination in tin mine tailings across Jos Plateau State, Nigeria. Human health risk assessments revealed minimal non-carcinogenic threats; however, elevated carcinogenic risks from lead ingestion were identified in children at Zawan A and Kuru A, with Zawan A also posing a notable risk to adults. These results underscore the urgent need for environmental monitoring, public health interventions, and the implementation of remediation strategies to mitigate exposure, particularly for vulnerable populations living near these dumpsites. Future research should explore long-term ecological impacts, effective remediation technologies, and policies to regulate tailings disposal and land use in mining communities.

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