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Occupational Health Risks of Dusts and Heavy Metals Contamination from the Artisanal Gold Mine of Buhemba, Tanzania

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Abstract: Exposure to heavy metals and dusts in artisanal and small scale mining activities is health issues among miners. This study was carried out at Buhemba artisanal and small scale gold mining sites situated in Mara region, Tanzania aims to assess the occupational health risks of small-scale gold miners who are exposed to dust and selected heavy metals. The respirable dust concentrations were measured by an aerosol monitor particle counter while the heavy metals were measured by an Energy Dispersive X-ray Fluorescence from pits and processing area. The average concentration of respirable particles in the milling areas ranged from 0.4 g/m^3 to 2.01 g/m^3 for particle sizes of 0.3µm, 0.5 µm, 1 µm, 5 µm and 10 µm with highest value found in particle size 0.3µm. The respirable dust particle concentration from pits ranged from 0.002 g/m^3 to 0.86 g/m^3 for the particle size of 0.3µm, 0.5 µm, 1 µm, 5 µm and 10 µm. Milling and pits respirable dust concentrations were generally higher than the WHO recommended value. The average concentration of Mercury (27.24 mg/kg and 6.41mg/kg), Arsenic (269.50mg/kg and 167.41mg/k) for milling and pits respectively were higher than the recommended value by US-EPA. The risk estimates revealed that children are more vulnerable to non-cancer risk due to exposure to heavy metals to Hazard Index values of 27.59 and 7.23 for the milling and pits respectively. The total carcinogenic risk for children in the milling and pit areas at 5.60E-03 and 2.70E-04 respectively, were above the acceptable risk for involuntarily exposed person at 10^{-6}. Total risk for adults in the milling and pit areas at 6.47E-04 and 4.04E-04 respectively, were above the acceptable risk for voluntarily exposed person at 10^{-4}.

Keywords: Artisanal and Small-Scale Gold Mining, Heavy Metals, Respirable Dust Particles, Risks Assessment

1. Introduction

Artisanal and small-scale gold mining (ASM) activities are widely conducted in many developing including Tanzania. These mining activities are conducted under unsafe conditions which results into health and environmental effects to workers and public. Although artisanal and small-scale gold mining (ASGM) activities are normally conducted under unsafe conditions, it produces about 20% of the total world gold supply [1, 2]. The mining activities of artisanal and small-scale gold use simple tools and method to extract gold from ore deposits. Mercury is mostly used to capture gold from the soil; as a result the process introduces and contributes approximately 20-30% of Mercury pollution on earth [2]. Furthermore, the Artisanal and small-scale gold mining activities can lead to increase the concentrations of heavy metals, such as (Cr), (Ni), (Cu), (Zn), (As), (Cd), (Hg) and (Pb) which occur naturally in the Earth's crust [3]. The heavy metals increment resulting in pollution in the environment and toxicity to human and animals [4].

For the past few decades, most of the attention has focused on pollution emanating from large scale mining. Most of the major gold mines have substantially upgraded their production technologies and have taken responsibility to remediate polluted lands in order to satisfy increasingly stringent regulatory requirements and public pressure [5]. However, environmental pollution related to artisanal and small scale mining (ASM) has been disregarded. The pollution prevention and remediation measures have been ineffective in most areas with small scale mining activities due to various reasons include economic, technological and legislatives barriers [6].

Since the mining industry in Tanzania is relatively new and rapidly expanding, there is a need to make studies to investigate the occupational health risks in Tanzania mines and it is appropriate to start with the small scale mines which are more vulnerable to occupational health risks than the large scale mines. The study [6] reported that 7,000,000 deaths occur worldwide due to occupational diseases every year. On top of that, fatalities and injuries are 20-25% annually, however, statistics on occupational health impact are unavailable but respiratory dust levels are known to be high in mines.

The Buhemba gold mine administration verifies the presence of reasonable six thousands of people in and around the site. It is noted that, about 9326 people are living within the mining area [7] and 63% of that population are directly engaged in mining [8]. It is expected that small scale miners at Buhemba in Mara are affected by high level of respirable dust particles and heavy metals which can become potentially dangerous if their exposure is not well controlled or in some cases the concentration exceeds certain threshold values. Therefore, this study intends to assess the risk associated with dust and heavy metals that affect miner's health and hence lowering their income and the national income at large. Buhemba gold mine as other mines in Tanzania has insufficient research data on health risks associated with dust and heavy metals from small scale mining activities and the general public awareness on the effects of environmental pollution due to mining.

2. Material and Methods

2.1. Study Area

The research was carried at Buhemba ASGM located in Mara region, Tanzania. (Figure 1). Mara is in the Lake Victoria Goldfields (LVGF); a gold-rich region of Tanzania [9]. As a result, the study location was chosen for its lengthy history of mineral extraction by both ASGM and LSGM in East Africa's gold-rich countries. The study locations may give valuable data on radioactivity levels and distribution, allowing researchers to assess the long-term effects of ASGM on the ecosystem and human health in the area.

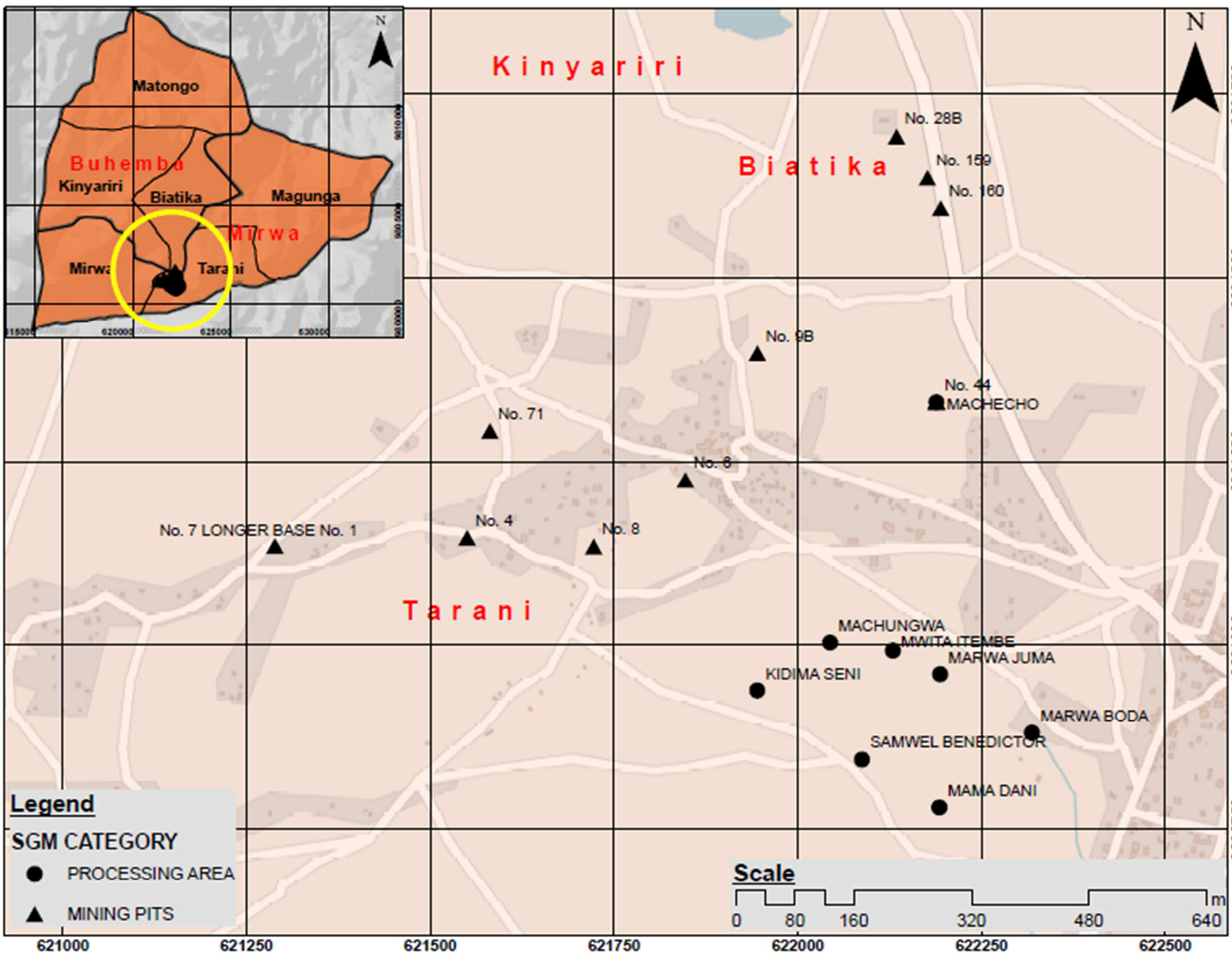

Figure 1. *Study Area.*

2.2. Respirable Dust Particles

Respirables air samples were measured at pits and milling areas. The respirables dust concentrations in the air were measured by using an aerosol monitor particle counter PCE-PCO. The dust monitor uses a built-in sampling pump to draw air through the device where the dust in the air scatters the light from a laser. The equipment can measure the particle size range from respirable and PM_{10}. The instrument was placed at a height of 1.5 m above the ground so as to reduce localized influences on the samples taken [10]. Three air samples were measured at each sample station and the presented value for each sample station is an average value. The readings were directly recorded from the instrument.

2.3. Soil Sample Collection

The soil samples were collected from milling and pits locations with the total samples of 21. The distribution of sampling locations was nine (9) and twelve (12) samples from milling and pits respectively. For each location three individual subsamples were collected at a depth of 0-20 cm and mixed together to make up a representative sample. The stainless-steel shovel was used to collect all soil samples from sampling location. The collected samples were placed in labeled polythene bags and transported to the Tanzania Atomic Energy Commission (TAEC) laboratory for Analysis.

2.4. Soil Sample Preparations

The collected soil samples were individually dried to reduce moisture contents and attain the constant weight in an oven at a temperature of about 100°C for 24 hours. Each sample was pulverized manually to very fine powder with an agate mortar and pestle and then sieved through 2 mm stainless steel sieve. The uniform pellets were created by pressing the homogenized mixture of sample at 15 tons to obtain cylindrical pellets of 32 mm diameter using a die pellet maker.

2.5. Laboratory Soil Measurements and Analysis

The heavy metals (Cr, Ni, Cu, Zn, As, Cd, Hg and Pb) were determined using polarized Energy Dispersive X-Ray Fluorescence (EDXRF). The EDXRF equipment has an inbuilt Turboquant (Tq 9232) algorithm for matrix effect correction which increases the excitation sensitivity of elements. Before ED-XRF analysis, the equipment software was calibrated. Measurement was done by loading each prepared pellet into a cleaned sample holder and then inserted in the X-ray excitation chamber. The analysis time was constant and equal to 15 minutes per reading for each sample. The heavy metal data presented in this study is the mean of the three measurements with ED-XRF instrument. The accuracy provided by the EDXRF technique was evaluated by using the Montana soil 2711A. The standard soil was prepared and analysed by using similar experimental conditions as the unknown sample. The average measured concentrations of SRM were compared with certified values of the same element in a sample, which facilitate the establishment of the level of agreement between the measured and certified values. The binder material was assessing to identify if there are any contaminations of the sample by the binder which may lead to reporting the high level of metal concentrations from the field soil samples. The binder material preparation employed the same procedure as soil sample and Soil Reference Material.

2.6. Human Health Risk Assessment

The human risk of heavy metals was assessed through ingestion, inhalation and dermal contact exposure routes methods proposed by U.S Environmental Protection Agency (USEPA) [11-13]. The doses exposed to human being were used in the estimation of both non-carcinogenic and carcinogenic risks. Both adults' artisanal and small-scale workers and children were involved in the assessment of health risk of heavy metals. The selected heavy metals for non-carcinogenic risk assessment were As, Cd, Pb and Hg and its selection was based on its potential to cause the health impacts [14]. Mercury was excluded in the carcinogenic calculations due to its unavailability of cancer slope factor. The doses exposed to human being were used in the estimation of both non-carcinogenic and carcinogenic risks. The risks associated with ingestion, inhalation and dermal contact of heavy metals through soil were estimated by using equation 1, 2 and 3 respectively.

$$D_{ing} = \frac{C \times IngR \times EF \times ED \times 10^{-6}}{BW \times AT} \quad (1)$$

$$D_{inh} = \frac{C \times InhR \times EF \times ED}{PEF \times BW \times AT} \quad (2)$$

$$D_{abs} = \frac{C \ \times SA \times FE \times AF \times ABS \times EF \times ED \times 10^{-6}}{BW \times AT} \quad (3)$$

where D_{ing}, D_{inh} is the respectively average daily intake from soil ingestion and inhalation in $mgkg^{-1}day^{-1}$, C is the concentration of heavy metal in soil (mg/kg), IngR and InhR is the ingestion and inhalation rate of soil in mg/day and m^3/day respectively, EF is the exposure frequency (days/year), ED is exposure duration (years), CF is the conversion factor in kg/mg, BW is the average body weight (kg) and AT is the averaging time (days). PEF is the particle emission factor in m^3/kg, EF, ED, BW and AT are as defined in Equation (1) above. Dabs is the exposure dose through dermal contact (mg/kg-day), C is absorbed dose (mg/cm^2-event), SA is the skin surface area available for contact (cm^2/day), FE is the fraction of the dermal exposure ration to soil, AF is the soil to skin adherence factor (mg/cm^2), ABS is the absorption factor (Unit less). Table 1 shows the exposure parameters used for health assessment through various exposure pathways for soil.

Table 1. *Exposure Parameters for children and Adult used in present study.*

Parameter	Unit	Child	Adult	Reference
Body (BW)	kg	15	70	[15]
Exposure duration (ED)	years	6	24	[16]
Exposure frequency (EF)	days/year	350	350	[17]
Ingestion Rate (IR)	mg/year	200	100	[16]
Inhalation Rate (IR_{air})	m^3/day	10	20	[11]
Particulate Emission Factor (PEF)	m^3/kg	$1.3*10^9$	$1.3*10^9$	[12]
Average Time (days)				
For carcinogenic	days	365*70	365*70	[18]
For non-carcinogenic		365*ED	365*ED	[18]
The skin adherence factor (AF)	mg/cm^2	0.2	0.07	[18]
Dermal exposure ratio (FE)	unit less	0.61	0.61	[18]
Dermal absorption Factor (ABS)	unit less	0.001 for other metals and 0.03 for Arsenic		[18]
Skin surface area	cm^2/day	2800	3300	[18]

Non carcinogenic health risks of small-scale gold miners who were exposed to As, Cd, Hg and Pb in soil via the ingestion, inhalation and dermal routes were expressed as the hazard quotient (HQ). For non-cancer risk, the calculated ingestion, inhalation and dermal contact doses for each elements is subsequently divided by the correspeonding reference dose (RfD) (mg/kg-day) to obtain a hazard Quotient (HQ) (or non-cancer rik) as indicated in Equation 4 [11].

$$HQ = \frac{D_{ing,inh,abs}}{RfD} \quad (4)$$

The effects to the population caused by exposure to the pathways concentrations is obtained by summing HQ of all metals which gives the Hazard Index (HI) as described by USEPA [11, 17]. The HI calculation equation is as shown in Equation 5 [11, 17].

$$HI = \sum_i HQ_i \quad (5)$$

For carcinogenic heavy metals, the risks are computed as the incremental propability of individual to develop cancer over a lifetime as a results to the exposure to carcinogenic elements using equation 6.

$$CR_{pathway} = \sum_{i=1}^{n} D_i CSF_i \quad (6)$$

where $CR_{pathway}$ is the unit risk of individual for lifetime (unit less), D_i are average daily intake (mg/kg/day) and CSF_i are cancer slope factor (mg/kg/day) for respective heavy metals. The total carcinogenic (cumulative) cancer for an individual is calculated from summation contribution of the individual heavy metals for all pathways using the Equation 7 [17].

$$Risk_{total} = Risk_{ing} + Risk_{inh} + Risk_{abs} \quad (7)$$

where $Risk_{ing}$, $Risk_{inh}$ and $Risk_{abs}$ are risks contributed by ingestion, inhalation and dermal contact pathways respectively. The Reference Doses (RfD) and Cancer Slope Factor (CSF) used in this study is as indicated in Table 2.

Table 2. *Reference doses (RfD) in (mg/kg-day) and Cancer Slope Factors (CSF) for the selected study heavy metals.*

Element	Oral RfD	Inhalation RfD	Ingestion RfD	Oral CSF	Inhalation CSF	Dermal CSF	Reference
Pb	3.50E-05	3.52E-03	0.000525	8.50E-03	4.20E-02	8.50 E-06	[13, 19, 20]
Cd	1.00E-03	2.86E-05	0.000025	5.00E-01	6.30 E+00	0.014	[18, 21-23]
Hg	3.00E-04	8.75E-05	2.10E-05	-	-	-	[18, 21-23]
As	3.00E-04	4.29 E-06	3.00E-04	1.5	1.50E+00	1.50E+00	[21-23]

3. Results and Discussion

3.1. Respirable Dust Particles

The dust particle concentrations were measured at the pits and milling areas. The average concentration of respirable particles in the milling areas were 2.01g/m^3, 1.02 g/m^3, 0.4 g/m^3, 0.57 g/m^3, 0.59 g/m^3 and 1.14 g/m^3 for particle sizes of 0.3µm, 0.5 µm, 1 µm, 5 µm and 10 µm 17 respectively. The highest particulate concentration was observed at Marwa Boda milling site with a concentration of 5.52 g/m^3 for particle size of 0.3µm (Figure 2). On the other hand, the respirable dust particles concentration from various working place in pits were 0.86 g/m^3, 0.58 g/m^3, 0.11 g/m^3, 0.02 g/m^3, 0.004 g/m^3 and 0.002 g/m^3 corresponding to particle size of 0.3µm, 0.5 µm, 1 µm, 5 µm and 10 µm. The highest particulate concentration of 3.1g/m^3 was observed at the working area of pit number 176 for particle size 0.5µm (Figure 3). The respirable dust concentration from both sampling points categories (milling and pits) were generally higher than WHO guideline limits for 24-hours at 50 µg/m^3. The dust exposures measured, raise concern of possible acute and chronic respiratory diseases and it calls for scientific intervention to ensure the miners safety.

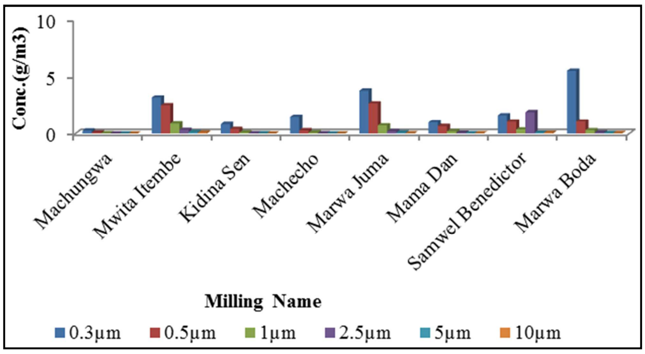

Figure 2. *Respirable dust particles concentration from Various Milling.*

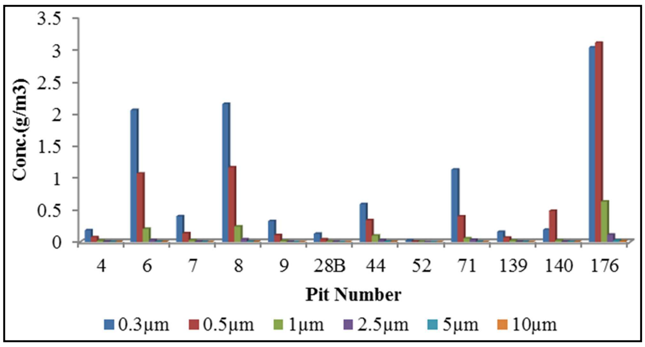

Figure 3. *Respirable dust particles concentration from Various Milling.*

3.2. Heavy Metals

The basic statistics of the measured heavy metal concentrations, including minimum and maximum values, average, median and standard deviation (SD) and mean world values are presented in Table 3. The spatial distribution of heavy metal concentrations in the soil samples was measured and compared with the earth metal concentrations in the earth's crust, Tanzania (National) Standards (TZS) and USEPA permissible levels [17, 24].

The mean concentrations of Hg from the milling and pits areas were found to be 27.24 mg/kg and 6.41mg/kg respectively. The values are far higher than the maximum allowed concentration of 1 mg/kg, recommended by US-EPA [16, 17]. The maximum measured Hg concentrations were 45.7 mg/kg at pits area and 41 mg/kg at milling areas. The observed maximum values were also very much higher than the maximum allowable Hg concentrations in soil. This scenario was highly contributed by the application Hg during amalgamation processes for gold recovery process by artisanal miners at Buhemba. Moreover, the concentration of Cr and Cd in the soil, from both milling and pits, were found to be higher than levels specified in the USEPA guidelines. The mean concentrations of Cu from pits were 299.70 mg/kg which is higher than Max USEPA acceptable level [16, 17]. For milling the mean concentration of Cu of 156.11 mg/kg was below the allowable concentration on the soil as stipulated by USEPA [16, 17]. The measured mean concentrations of Arsenic were 269.50mg/kg and 167.41mg/kg for milling and pits respectively. The measured values were higher than acceptable arsenic limit of 20 mg/kg as recommended by the European community [25, 26]. The arsenic concentrations range from 24.43mg/kg to 659.43 mg/kg for both milling and pits, this is also higher than allowable concentration in the soil of 20 mg/kg. Furthermore, Pb was found at an average concentration of 8.76 mg/kg and 9.41 mg/kg from milling and pits respectively, which is below the maximum allowed Pb concentration of 200 mg/kg, recommended by USEPA [16, 17]. The maximum measured Pb concentration at 23.85 mg/kg and 30.9mg/kg for milling and pits respectively, was lower than the maximum allowed Pb concentration in soil.

Table 3. *Mean (mg/kg), Standard Deviation (STD), Minimum and Maximum Concentrations of Elements at milling Area and Pits Areas Compared to Permissible Levels from Tanzania (National) Standards (TZS) and USEPA.*

Sampling Area	Statistic Measured Values	Cr	Ni	Cu	Zn	As	Cd	Hg	Pb
Milling Area	Average	103.79	43.24	156.11	125.93	269.50	5.98	27.24	8.76
	STDEV	39.12	37.02	140.42	110.61	185.26	0.23	12.92	7.03
	Min	32.1	2.7	48.15	27.73	24.43	5.76	4.85	1.57
	Max	164.75	125.45	501	406.4	659.43	6.48	41	23.85
	Median	103.79	38.09	135.25	110.61	196.37	5.98	29.43	7.1
	Mean World Conc.	100		30	50		0.06	0.03	10
	Max TZS			200	150		1		200
	Max USEPA	11		270	1100		0.43		200
Pits Area	Average	206.20	142.20	299.70	403.12	167.41	5.99	6.41	9.41
	STDEV	89.10	80.56	130.73	267.86	106.19	0.37	10.20	7.84
	Min	56.5	24.25	41.3	43.4	54.1	5.375	1.9	1.6
	Max	430.8	333.3	506.9	942.7	432.9	6.8	45.7	30.9
	Median	197.25	124.75	266.19	306.90	147.47	5.98	3.09	8.44
	Mean World Conc.	100		30	50		0.06	0.03	10
	Max TZS			200	150		1		200
	Max USEPA	11		270	1100		0.43	1	200

Higher concentrations of Hg, Cd, Cr and As observed at Buhemba SSM signify that soils at Buhemba mines may pose health threat to human beings and ecology. Usually, accumulation of heavy metals in soils leads to increased bio-concentration and bioaccumulation in plants, livestock and humans, mostly through the food chain [27]. Consumption of food polluted by heavy metals has been connected to health hazards that endanger human life; which includes a wide range of carcinogenic diseases such as kidney, liver as well as brain damage [28]. It is anticipated that, the risks to human and environment associated with this high level of heavy metals at Buhemba will linger, unless intentional efforts are instituted with a purpose.

3.3. Non-Cancer Risk from Heavy Metals

The non-cancer hazards quotient for ingestion, inhalation and dermal contact risk were calculated for children and adult age groups and presented in Table 4 and Table 5 respectively.

The Hazard Index (HI) for children and adult from exposure of four mentioned heavy metals in the milling and in the pits are indicated by Figure 4.

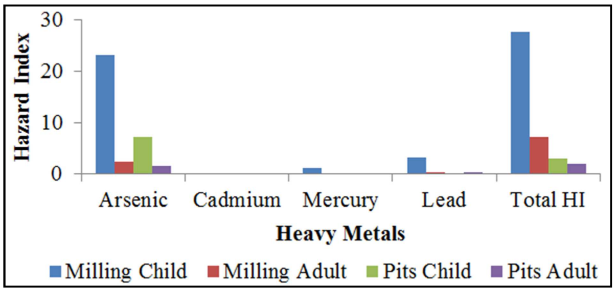

Figure 4. *Heavy Metals and Total Hazard Index for milling and Pits Areas.*

Table 4. *Non-Cancer Risk for Children.*

	Element	Ding	Dinh	Dabs	HQing	HQinh	HQabs
Milling area	Arsenic	3.45E-03	1.33E-07	2.89E-04	11.49	3.09E-02	11.58
	Cadmium	7.65E-05	2.94E-09	2.14E-07	7.65E-02	1.03E-04	8.56E-03
	Mercury	3.48E-04	1.34E-08	9.75E-07	1.16	1.53E-04	4.64E-02
	Lead	1.12E-04	4.31E-09	3.14E-07	3.2	1.00E-03	5.97E-04
Total							
Pits Area	Arsenic	3.82E-08	8.23E-08	1.80E-04	1.27E-04	1.92E-02	7.19
	Cadmium	1.37E-09	2.95E-09	2.14E-07	1.37E-06	1.03E-04	8.58E-03
	Mercury	1.46E-09	3.15E-09	2.29E-07	4.88E-06	3.60E-05	0.0109272
	Lead	2.15E-09	4.63E-09	3.37E-07	6.14E-05	1.08E-03	0.0006417
Total							

Table 5. *Non-Cancer Risk for Adult.*

Area	Element	Ding	D_{inh}	Dabs	HQing	HQinh	HQabs
Milling area	Arsenic	4.00E-04	6.15E-08	2.77E-05	1.33	1.43E-02	1.11
	Cadmium	8.97E-06	1.37E-09	2.05E-08	8.87E-03	4.77E-05	8.20E-04
	Mercury	4.04E-05	6.22E-09	9.34E-08	1.30E-01	7.11E-05	4.45E-03
	Lead	1.30E-05	2.00E-09	3.00E-08	3.71E-01	4.66E-04	5.72E-05
Total							
Pits Area	Arsenic	2.48E-04	3.82E-08	1.72E-05	8.28E-01	8.91E-03	6.89E-01
	Cadmium	8.89E-06	1.37E-09	2.05E-08	8.89E-03	4.78E-05	8.20E-04
	Mercury	9.51E-06	1.43E-09	2.20E-08	3.17E-02	1.67E-05	1.05E-03
	Lead	1.40E-05	2.15E-09	3.23E-08	3.99E-01	5.01E-04	6.14E-05
Total							

The findings indicated that the Hazard Index (HI) for children population from exposure of four mentioned heavy metals in the milling and pits are above 1. The Arsenic showed highest value in the milling and pits with HI value of 23.09 and 7.21 respectively. Total HI from all heavy metals and all exposure routes are also higher than 1. The HI for adults' population in the milling and pits areas were also above 1, meaning that both milling and pits activities may cause negative health impacts for both children and adult. The children are more vulnerable to the negative risks associated with the exposure to heavy metals. The findings are related to the [29] study findings conduced in artisanal gold mine in Nigeria, which observed that, the mining activities are posing non-cancer risk for children.

3.4. Cancer Risks from Heavy Metals

The findings indicated that Arsenic has high cancer risk for both areas than other heavy metals with values of 5.68E-03 and 2.70E-04 for milling and pits areas respectively as indicated in Table 6. For adults, results revealed that Arsenic has high risk for both milling and pits compared to other elements with respectively values 6.42E-04 and 3.99E-04 as indicated in Table 6. Carcinogenic risks for children and adults' results indicated that total cancer risks for all heavy metals, three exposure ways and both milling and pits areas are higher than the recommended EPA upper limit risk value of 1×10^{-4} and lower limit risk value of 1E-06 as indicated in Figure 5. The children are more at risks than adults.

Table 6. *Carcinogenic risks for children via Three Pathways Routes.*

Area	Element	Pathways Cancer Risks			Sum of Cancer Per Element and Pathways
		Ingestion	Inhalation	Dermal absorption	
	Arsenic	5.17E-03	1.99E-07	4.34E-04	5.68E-03
Milling area	Cadmium	2.25E-13	1.85E-08	3.00E-09	2.15E-08
	Lead	9.52E-07	1.81E-10	2.67E-12	9.52E-07
	Arsenic	5.73E-08	1.23E-07	2.70E-04	2.70E-04
Pits Area	Cadmium	6.84E-10	1.86E-08	3.00E-09	2.2E-08
	Lead	1.83E-11	1.94E-10	2.86E-12	2.15E-10
Total					

Table 7. *Carcinogenic risks for adults via three Pathways Routes.*

Area	Element	Pathway Cancer Risks			Sum of Cancer Per Element and Pathways
		Ingestion	Inhalation	Dermal absorption	
	Arsenic (As)	6.00E-04	9.23E-08	4.16E-05	6.42E-04
Milling Area	Cadmium (Cd)	4.43E-06	8.60E-09	2.87E-10	4.45E-06
	Lead (Pb)	1.11E-07	8.4E-11	2.55E-13	1.11E-07
	Arsenic (As)	3.73E-04	5.73E-08	2.58E-05	3.99E-04
Pits	Cadmium (Cd)	4.44E-06	8.62E-09	2.87E-10	4.45E-06
	Lead (Pb)	1.19E-07	9.02E-11	2.74E-13	1.19E-07

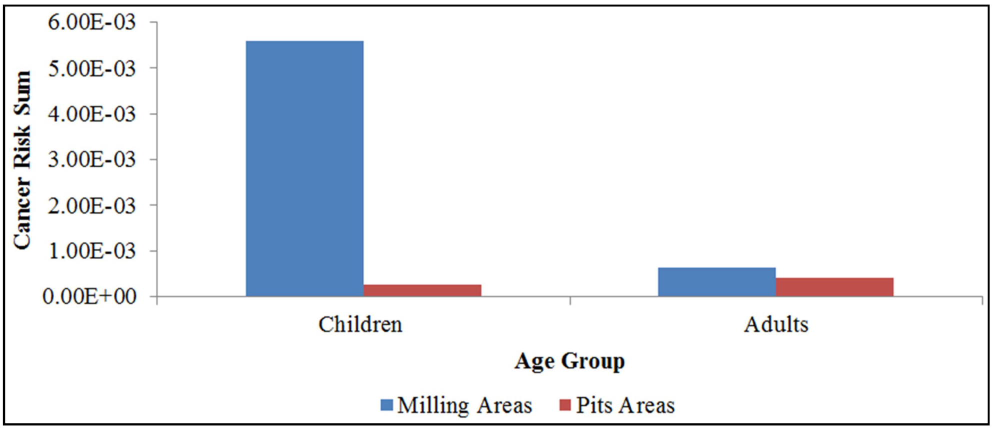

Figure 5. *Total Cancer Risk via Inhalation and Ingestion and dermal contact for Children and Adults.*

4. Conclusion

The results showed that dust particle concentrations at the pits and milling areas are higher than the WHO recommended values. Pit number 176 was found to have highest value of 3.1g/m^3 which is higher than WHO guideline limits for 24-hours at 50 µg/m^3. This may cause the health problem to the mining workers due to high exposure to the particulate dust. The carcinogenic heavy metals results showed that the concentrations are higher than allowable limit. The average Hg values are 27mg/kg and 6mg/kg for milling and pits respectively, higher than the USEPA maximum allowable limit. The concentration of Cr and Cd in the soil, from both milling and pits, were found to be higher than levels specified in the USEPA allowable limit. The observed higher concentrations at Buhemba SSM signify that soils at Buhemba mines may pose health threat to human beings and ecology. The study furthermore showed that children are more vulnerable to non-cancer risk due to exposure to heavy metals with Hazard Index values of 27.59 and 7.23 for the milling and pits respectively. Total carcinogenic risk for children and in the milling and pits areas were above the acceptable risk for involuntarily exposed person at 10-6 and voluntarily exposed person at 10-4. Based on the findings of this study, it can be concluded that soils in the Buhemba artisanal gold mining are seriously polluted by carcinogenic heavy metals, especially from Hg, Cd and Cr. The findings demonstrate the serious need to put in place regulations to protect residents, especially children from heavy metal pollution in the environment.

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