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Health risk assessment of dust samples (indoor and outdoor) collected from houses around a mining area in Brits, South Africa

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ABSTRACT

Mining activities are major contributors to metallic dust found in households, both indoor and outdoor. The present study determines the concentrations of trace metals in indoor and outdoor dust samples collected from houses around a mining area with a view to establishing their impact on human health. Eighty dust samples were collected from households near a mining area and were analysed for trace metal concentrations using inductively coupled plasma mass spectrometry (ICP – MS). The metal concentrations were in the order Fe > Mg > Mn > Cr > Zn > As > Ni > Hg > Cd > Cu for indoor and Mg > Fe > Cu > Cr > As > Zn > Hg > Cd > Ni > Mn for outdoor dust. The concentration of metals Hg, Cr and As were higher than the permissible limit of 0.9 µg/g, 6.5 µg/g and 5.8 µg/g, respectively set by South Africa and that of Cd exceeded the limit of 3.0 µg/g set by World health organisation (WHO) for human exposure. The result showed that there was a correlation in the concentration, between Fe and Mn, Fe and Cr, Fe and As, Fe and Ni, as well as with Fe and Cd from indoor dust samples. Correlation was also observed between Mg and Mn, Mg and Cr, Mg and Zn, Mg and As, Mg and Ni ($p < 0.01$) and Fe and Cd from outdoor dust samples. Correlation was also established between outdoor Mg and As, with indoor Hg in the dust samples. The pollution assessments indicated that households were within the range of $0 < Igeo < 1$, which is classified as unpolluted to moderately polluted. The results also showed that the pollution was due to anthropogenic sources. It is concluded that exposure to mining activity may pose a threat to human health, especially with regard to trace metal concentrations that have exceeded the permissible limit for human exposure. The health risk assessment for humans indicated that there might be a future concern for human health over time.

KEYWORDS: trace metals, mining activities, dust, health risk, Brits.

1. INTRODUCTION

Mining activities in South Africa have been implicated as one of the major contributors of trace metals in the environment [1, 2]. It has also been reported that these mining activities may increase the concentrations of trace metals in soil and plants around the vicinity if unchecked or uncontrolled [2, 3].

Mining activities may release toxic elements through tailings, gangue minerals and subsequent smelting operations into the soil [4-7]. These toxic metals are also introduced into the food chain through the soil and eventually enter and accumulate in the human body through both direct and indirect pathways [8]. Mining operations also cause air pollution through particulate matter or dust that is transported by the wind as a result of excavations, blasting, and transportation of materials. Once pollutants enter the atmosphere, they undergo

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either physical or chemical changes until they reach a receptor [9].

Dust from mining area is typically formed by grinding metal during the process of drilling. Certain types of metal dust can be extremely toxic, particularly if the metal is comprised of trace metals like cobalt (Co), lead (Pb), or nickel (Ni). These metals can make their way into households, through wind or by being carried on clothing materials such as work suits [10]. Once it's inside the house, this indoor dust acts as a reservoir for environmental pollutants like trace elements, which may accumulate indoor overtime and potentially affect human health, especially for individuals living in areas around mining areas [11, 12].

Environmental impact assessments of mining projects often underestimate the potential health risks to mankind [13]. Dust containing trace metals resulting from mining processes may be inhaled, ingested or attached to the dermal layer of the skin [14]. Trace metals are part of a large group of air pollutants called air toxics, which upon inhalation or ingestion can inflame, trigger sensitivity and even cause scars on the lung tissue. They can also be responsible for a range of health problems such as cancer, neurotoxicity and immunotoxicity [15-20]. Workers exposed to metal dust can experience irritation in the lungs and throat [11, 12]. Symptoms of toxicity depend on the type of metal, the dose absorbed and whether or not the exposure was acute or chronic [21].

Some trace metals play a vital biological function in both animals and plants [22]. However, due to their chemical coordination and oxidation-reduction properties, they are capable of hindering mechanisms such as transport, homeostasis, compartmentalization and binding to their obligatory cell constituents. These metals dislocate and displace original trace metals from their binding sites by binding to protein sites that which are not made for them thereby resulting in cell malfunction and eventually cell toxicity [23].

Some of these metals such a Pb, Cd, Hg, Zn, and Cr are linked to different human health disorders which include disorders of the nervous system, cardiovascular, blood and bone diseases, tremors and gingivitis as well as kidney failure. They are also known to act as human mutagens and carcinogens [24, 25]. There is substantial attention given to the study of urban air pollution caused by metals, roadside dusts and soils. However, there is little information on the presence of trace metals in house yards, contributing to indoor dust, especially in areas around mining activities.

Dust has been linked to various types of diseases especially due to the contents that are present in them. For instance, the study by Olowoyo *et al*. [2, 26], reported that dust may contain toxic trace metals that are above the recommended limit and may be carcinogenic over time. A similar study by [27], also showed that dust particles may pose a carcinogenic risk to humans as a result of anthropogenic activities which include mining.

In South Africa, mining activities are one of the major contributors to the growth of the economy; in South Africa mining alone is responsible for 451,427 jobs [28]. It is always a common occurrence to see heaps of excavated soil with uncovered waste around mining areas with informal settlements around these areas. When the wind blows, it is possible for the wind to carry dust particles from these excavated land into the nearby houses thereby polluting the environment around that area with mine dust. Apart from this, miners do stay in the same house with their immediate family members and dust that are on their clothes may increase the level of pollutants in the particular house [10]. The dangers of exposure to mining activities, especially exposure of those living around the mines to dust, is that trace metals that are contained in the dust particles may cause the community to become ill.

The problem of trace metal pollution in mining areas has received considerable attention in recent years because of the epidemiological evidence of lung cancer especially in mine workers [29]. However, there is limited information on trace metal exposure due to dust blown from mining activities and the human health risk assessment in the households near mining activities in Brits. Therefore, it is due to this background that the current study intends to check the concentrations of trace metals in indoor and outdoor dust samples as well as to assess the human health risk of exposure to mining activities in houses around the mining areas of Brits.

2. METHODS

2.1. Study area

The study was carried out in an informal settlement near a mining industry situated in Brits/North West, South Africa [25°44′46″S 28°11′17″ E]. The area is densely populated with housing structures constructed of zinc material. The informal settlement is situated directly opposite to a chrome mine, where the main road R511 linking Brits and Pretoria, separates the residence and the mine.

2.2. Sample collection and analysis

Eighty (80) dust samples were collected from 40 households, where 2 samples were collected from each household (1 indoor and 1 outdoor). Settled indoor dust samples that may have been trapped during opening and closing of windows and doors were collected by gently sweeping through all the rooms in the house, including the area under the bed, using a clean plastic brush and tray. All the samples were collected with foreign particle, and debris. After each collection, the brush and tray were wiped clean to minimise contamination. The collected samples were placed in a plastic container and labelled. The samples were then taken to the lab for further preparations.

For outdoor dust samples, a similar method of collection was used; however, only the area around the house including, door steps and window sills were swept gently with the use of a clean plastic brush and tray. The tray and brush were again wiped after each collection to minimise the transmission of contaminant. The samples including foreign objects that were obtained during collection, were placed into plastic containers with the different particles, then labelled and taken to a laboratory.

In the laboratory, the larger particles and foreign objects found from both indoor and outdoor samples were removed from the collected samples by sieving the samples through a large sieve with holes of 2 mm in diameter. Then the dust samples were air-dried on a plastic sheet for a period of 2-3 days. Later, the samples were ground using a pestle and a mortar to obtain a homogenous mixture then sieved with a sieve size < 2 mm in diameter to eliminate larger particles. A respirator mask and powderless gloves were worn as precautionary measures during the process of sample collection, preparation and laboratory analysis.

From the prepared dust samples, 5 g was weighed using a balancing scale. A two-acid digestion method was used. For each sample (outdoor and indoor), 5 g of dust was placed in a 50 ml Erlenmeyer flask and 3 ml of perchloric acid ($HClO_4$) and 10 ml of nitric acid (HNO_3) were added to the dust samples then digested. After the digestion was completed the samples were allowed to cool down and then filtered using a filtration apparatus consisting of a filter paper, glass beaker and funnel. The resulting solution was then diluted to 50 ml in a volumetric flask with deionised water and kept in a cool environment. The samples were analysed using inductively coupled plasma mass spectrometry (ICP – MS) for trace metal content. For the purpose of quality assurance, certified reference materials (CRM) purchased from NIST (PS-1 COOMET COD 310b) was digested in the same way and analysed for presence of trace metals. To ensure accuracy of results obtained, analysis of the sample was carried out in triplicate and mean values with standard deviation was used as the final results.

2.3. Pollution assessment

The pollution assessment of the dust was carried out using the pollution index (Pi) and the geo-accumulation index (Igeo) method. The formula used for the calculation of the pollution index was

$$Pi = Ci/Si.$$

In the formula, Ci represents the concentration of trace metal (i) in dust samples and Si indicates the relevant standard value for this metal [30, 31].

The contamination level of the dust samples, using Pi, was classified into four grades: $Pi < 1$: unpolluted, $1 \leq Pi < 2$ is regarded as slight pollution, $2 \leq Pi < 3$ regarded as medium pollution, and $Pi \geq 3$ is regarded as heavy pollution [32].

The level of contamination for the sample was also calculated using the geo-accumulation index [33]. In the geo - accumulation index, the degree of contamination is calculated using the following formula:

$$I_{geo} = \log_2 (Cn / 1.5Bn)$$

In the formula, C represents the measured concentration of metal and B represents the geo - chemical background value. A factor of 1.5 is used to include possible variation of background

values due to lithogenic effects [33] and an index of enrichment is [34] as follows:

Class	I_{geo} Value	Sediment quality
0	≤ 0	Unpolluted
1	0 < Igeo < 1	Unpolluted to moderately polluted
2	1 < Igeo < 2	Moderately polluted
3	2 < Igeo < 3	Moderately to strongly polluted
4	3 < Igeo < 4	Strongly polluted
5	4 < Igeo < 5	Strongly polluted
6	5 < Igeo	Extremely polluted

2.3.1. Health risk assessment

Human health risk assessment is a process used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals [35]. The risk assessment process is made up of four basic steps:

Hazard identification - aims to investigate chemicals that are present at any given location, their concentrations, and spatial distribution [35].

Exposure assessment - to measure or estimate the intensity, frequency, and duration of human exposures to an environmental contaminant [36]. Exposure assessment will be carried out by measuring the average daily intake (ADI) of trace metals through inhalation, ingestion and dermal contact by adults from the study area.

Toxicity assessment - estimates the toxicity due to exposure levels of chemicals [34].

Risk characterization - predicts the potential cancerous and non-cancerous health risk of adults in the study area by integrating all the information gathered to arrive at quantitative estimates of cancer risk and hazard indices [36]. ADI (mg/kg-day) for various exposure pathways was calculated using the following exposure equations (1, 2 and 3) [37].

Inhalation of trace metals through dust particles:

$$ADI_{inh} = C_{dust} \times InhR \times EF \times ED/ BW \times AT \times PEF \quad \text{(Equation 1)}$$

Ingestion of trace metals through dust particles:

$$ADI_{ing} = C_{dust} \text{ x } IngR \text{ x } EF \text{ x } ED/ BW \text{ x } AT \text{ x } 10^{-6} \quad \text{(Equation 2)}$$

where ADI_{inh} is the average daily intake of trace metals inhaled from dust in mg/kgday, C is the concentration of trace metals in dust in mg/kg, Inh/IngR is the inhalation rate in m^3/day, PEF is the particulate emission factor in m^3/kg, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg (data obtained from a survey done in the study area included in Table 1 and AT is the time period over which the dose is averaged in days.

The equation for dermal contact with dust particles is as follows:

$$ADI_{dems} = C_{dust} \times SA \times FE \times AF \times ABS \times EF \times ED \times CF/ BW \times AT \quad \text{(Equation 3)}$$

where ADI_{dems} is the exposure dose *via* dermal contact in mg/kg/day. C is the concentration of trace metal in dust in mg/kg, SA is exposed skin area in cm^2, FE is the fraction of the dermal exposure ratio to dust, AF is the dust adherence factor in mg/cm^2, ABS is the fraction of the applied dose absorbed across the skin. EF, ED, BW, CF and AT are as defined earlier in Equation (1 and 2).

Generally, the higher the hazard quotient (HQ) value above unity (1), the greater the level of concern. Thus, HQ ≤ 1 proposes unlikely adverse health effects, whereas HQ > 1 proposes the probability of contrary health effects. In general, the cancer risks lower than 10^{-6} are considered to be negligible, and cancer risks above 10^{-4} are considered unacceptable by most international regulatory agencies [37, 38]. The value 10^{-6} is also considered the carcinogenic target risk by the [39].

2.3.2. Non-carcinogenic risk assessment

Non-carcinogenic hazards are characterized by a term called hazard quotient (HQ). HQ is expressed as the probability of an individual suffering an adverse effect. It is defined as the quotient of ADI or dose divided by the toxicity threshold value, which is referred to as the chronic reference dose (RfD) shown in Table 2, in mg/kg-day of a specific trace metal and is represented in the below equation [37].

Table 1. Exposure parameters for the health risk assessment through various exposure pathways for dust [36, 40].

Parameter	Unit	Adult
Body weight (BW)	Kg	75
Exposure frequency (EF)	days/year	350
Exposure duration (ED)	Years	10
Ingestion rate (IR)	mg/day	100
Inhalation rate (IRair)	m^3/day	20
Skin surface area (SA)	cm^2	5800
Dust adherence factor (AF)	mg/cm^2	0.07
Dermal Absorption Factor (ABS)	None	0.1
Dermal exposure ratio (FE)	None	0.61
Particulate emission factor (PEF)	m^3/kg	1.3×10^9
Conversion factor (CF)	kg/mg	10^{-6}
Average time (AT) :		
For carcinogens	Days	365 × 70
For non-carcinogens		365 × ED

$$HQ = ADI/RfD \quad \text{(Equation 4)}$$

2.3.3. Carcinogenic risk assessment

The carcinogenic risk assessment estimates the probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The equation for calculating the excess lifetime cancer risk is [37]:

$$Risk_{pathway} = \sum (n\ k=1)\ ADI_k CSF_k \quad \text{(Equation 5)}$$

where $Risk_{pathway}$ is the unit-less probability of an individual developing cancer over a lifetime. ADI_k (mg/kg/day) and CSF_k $(mg/kg/day)^{-1}$ are the average daily intake and the cancer slope factor, respectively, for the $_k$th trace metal, for n number of trace metals. The slope factor converts the estimated daily intake of the trace metal averaged over a lifetime of exposure directly to incremental risk of an individual developing cancer [37].

2.4. Statistical analysis

A Statistical Package for Social Sciences (SPSS) version 26.0. was used for data analysis and one-way analysis of variance (ANOVA) was used to test significant differences among the mean concentrations of trace metals in the samples obtained from different households.

3. RESULTS AND DISCUSSION

3.1. Trace metal concentrations

A total of 80 dust samples were analysed for trace metal concentrations and the results are represented in Table 3. The trace metal concentrations were in the order Fe > Mg > Mn > Cr > Zn > As > Ni > Hg > Cd > Cu for indoor dust and Mg > Fe > Cu > Cr > As > Zn > Hg > Cd > Ni > Mn for outdoor dust. The highest elemental metal concentration was reported for Fe at 903.00 ± 616.97 µg/g and the lowest was that of Cu at 3.42 ± 2.10 for indoor dust. Similarly, for outdoor dust samples, the highest metal concentration was that of Fe at 876.07 ± 139.66 and the lowest was that of Cu which was 2.43 ± 17.87 µg/g. The metal concentration for Cu in some households exceeded the permissible limit of 16 µg/g, set by WHO for outdoor dust samples (Table 4).

The high levels of Fe observed in the area could be attributed to the mining activities taking place in the study site. The residential area is situated next to the mine and is only separated from the mining activities, by the main road. The high levels of Cu could be as a result of vehicular emissions and tire wear, since the study area is located along the main road joining Brits and

Table 2. Reference doses (R*f*D) in mg/kg-day and cancer slope factors (CSF) for the different trace metals [36, 40, 41].

Heavy metal	Oral R*f*D	Dermal R*f*D	Inhalation R*f*D	Oral CSF	Dermal CSF	Inhalation CSF
As	3.00E-04	3.00E-04	3.00E-04	1.50E+00	1.50E+00	1.50E+01
Pb	3.60E-03	-	-	8.50E-03	-	4.20E-02
Hg	3.00E-04	3.00E-04	8600E-05	-	-	-
Cd	5.00E-04	5.00E-04	5.70E-05	-	-	6.30E+00
Cr(VI)	3.00E-03	-	3.00E-05	5.00E-01	-	4.10E+01
Co	2.00E-02	5.70E-06	5.70E-06	-	-	9.80E+00
Ni	2.00E-02	5.60E-03	-	-	-	-
Cu	3.7.00E-02	2.40E-02	-	-	-	-
Zn	3.00E-01	7.50E-02	-	-	-	-

Pretoria [42-44]. In addition to mining activities taking place in the study site, Brits is predominantly an agricultural site, which could account for high concentrations of Mg [recorded at 378.37 ± 161.24 µg/g (indoor) and 278.15 ± 439.60 µg/g (outdoor)] used in fertilisers and other agricultural products. The elements may have found their way into households through metal dust swept by wind or by being carried by residents on clothes into the houses [44].

The mean concentrations of As were 19.16 ± 8.64 µg/g and 15.57 ± 10.04 µg/g in indoor and outdoor dust samples, respectively, while Hg recorded 4.51 ± 5.58 µg/g and 3.37 ± 2.95 µg/g in indoor and outdoor dust samples, respectively. The metal concentrations exceeded the permissible limit of 5.80 µg/g (As) and 0.93 µg/g (Hg) set by South Africa. According to [45], As and Hg can be found naturally in the environment and some geographical areas have naturally high levels of As in the soil. Furthermore, in a study conducted by [46] the concentration of As was found to be higher in areas affected by metalliferous mineralisation and a significant contributor to As concentrations was found to be associated with mining activities. In addition, the high concentrations of As in the present study area could also be attributed to cigarette smoking, which is highly common among residents in the study area. Mercury has been reported in air, water and soil in a study [47]. Furthermore, high levels of Hg around a mining site for sluicing of ore for recovering of gold with the aid of liquid Hg, a process which increases the concentration of metal pollutants, has also been reported [47]. High Hg concentrations recorded for indoor dust may be as a result of burning of fossil fuel inside the house for food preparation and the preparation of cosmetic products [48, 49].

The mean concentration of Cr recorded was 36.34 ± 23.00 µg/g for indoor and 24.72 ± 14.76 µg/g for outdoor dust samples. The concentrations of Cr in this study were similar to the findings by the study in [50], which was conducted within an active mine in Falansa. This suggests that the sources for the high Cr concentrations observed are the ongoing mining activities in both areas.

The high levels of Cd in the dust samples were 4.33 ± 1.82 µg/g (indoor) and 4.07 ± 2.72 µg/g (outdoor). These high concentrations of Cd may be attributed to mining activities, as demonstrated in a study [51]. In addition to mining activities, high levels of Cd in indoor samples may have been present as a result of burning firewood for cooking and providing heat, while tire wear may account for high concentrations observed in outdoor samples, since the study area is located along the busy main road joining the Brits town to the city of Pretoria. In addition, high levels of Cd, especially in indoor samples, could be as a result of household products including paint.

A positive correlation was established between Fe with Mg, Mn, Cr As, Ni and Cd for both indoor nd outdoor dust samples (Tables 5 and 6). In the

Table 3. Mean concentrations (µg/g) of trace metals in indoor and outdoor dust (n = 80).

Trace metal		Zn	Ni	Cu	Mn	Mg	Hg	Fe	Cr	Cd	As
INDOOR	Mean ± SD	30.79 ± 37.2	6.33 ± 3.62	3.42 ± 2.1	38.78 ± 19.1	378.37 ± 161.24	4.51 ± 5.58	903.00 ± 616.97	36.34 ± 23	4.33 ± 1.82	19.16 ± 8.64
	Min	0.69	1.56	0.692	6.61	92.3	N.D	80.40	5.93	1.1	4.13
	Max	192	17.79	9.28	94.9	757	31.4	3020.00	101	7.82	36.5
OUTDOOR	Mean ± SD	13.15± 7.93	4.68 ± 1.85	2.43 ± 17.87	24.59 ± 1.1	278.15 ± 439.6	3.73 ± 2.95	876.07 ± 139.66	24.72 ± 14.76	4.07 ± 2.72	15.57 ± 10.04
	Min	2.97	1.37	0.20	0.425	0.987	N.D	1.55	N.D	0.21	N.D
	Max	37.5	8.14	89.3	4.51	2150	16.3	649.00	80.8	15.8	52.2

Table 4. Maximum permissible limit of trace metal concentrations in soil (μg/g) for South Africa based on FAO/WHO guidelines [54].

COUNTRY	Trace metals						
	As	**Hg**	**Cd**	**Cr**	**Cu**	**Zn**	**Ni**
FAO/WHO guidelines	20	NA	3	100	100	300	50
South Africa	5.8	0.93	7.5	6.5	16	240	91

Table 5. Correlation coefficient matrix of trace metals in indoor dust samples collected from a mining area in Brits.

	Fe Indoor	**Mg Indoor**	**Mn Indoor**	**Cr Indoor**	**Zn Indoor**	**As Indoor**	**Ni Indoor**	**Hg Indoor**	**Cd Indoor**	**Cu Indoor**
Fe Indoor	1	0.65**	0.73**	0.90**	0.26	0.62**	0.93**	0.18	0.60**	0.34*
Mg Indoor	0.65**	1	0.88**	0.67**	0.45**	0.86**	0.78**	0.20	0.87**	0.69**
Mn Indoor	0.73**	0.88**	1	0.78**	0.41**	0.76**	0.87**	0.09	0.73**	0.55**
Cr Indoor	0.90**	0.67**	0.78**	1	0.30*	0.60**	0.92**	-0.03	0.54**	0.39*
Zn Indoor	0.26	0.45**	0.41**	0.30*	1	0.51**	0.31*	0.17	0.47**	0.49**
As Indoor	0.62**	0.86**	0.76**	0.60**	0.51**	1	0.69**	0.17	0.89**	0.72**
Ni Indoor	0.93**	0.78**	0.87**	0.92**	0.31*	0.69**	1	0.08	0.68**	0.50**
Hg Indoor	0.18	0.20	0.09	-0.03	0.17	0.17	0.08	1	0.34*	-0.04
Cd Indoor	0.60**	0.87**	0.73**	0.54**	0.47**	0.89**	0.68**	0.34*	1	0.73**
Cu Indoor	0.34*	0.69**	0.55**	0.39*	0.49**	0.72**	0.50**	-0.04	0.73**	1

$p < 0.01$ (**); $p < 0.05$ (*)

a indoor samples, iron was also positively correlated with Cu ($p < 0.05$). A positive correlation was also established, between Mg and Mn, Mg and Cr, Mg and Zn, Mg and As, Mg and Ni and also between Mg and Cd for both indoor and outdoor dust samples. There was a positive correlation observed for indoor dust samples of Hg with outdoor dust samples of Mg and As ($p < 0.05$). It was observed that as the concentrations Mg and As from the outdoor dust samples increased, there was also an increase in the concentration of Hg, which was from the indoor dust samples.

However, a negative correlation was also established from indoor dust samples of Fe with outdoor dust samples of Ni ($p < 0.05$). This shows that as the concentrations of Fe from outdoor dust samples increased, there was a decrease observed in the concentrations of Ni from outdoor dust samples. The results also showed that Mg from indoor dust samples has a negative correlation with Mn, Cr, Ni, Hg, Cd and Cu from outdoor dust samples ($p < 0.05$). A negative correlation was established between Mn from indoor dust samples and Fe, Mn, Mg, Cr, As, Ni, Cd and Cu from outdoor dust samples ($p < 0.01$).

Chromium from indoor dust samples has a negative correlation with outdoor dust samples of Fe, Mn, Cr, Ni and Cd ($p< 0.05$). A negative correlation was also established between Ni from indoor dust samples and Ni ($p< 0.01$) and Cd ($p< 0.05$) from outdoor dust samples. It was also established that a negative correlation exists for indoor dust samples of Cu with outdoor dust samples of Mn, Zn, As, Hg and Cd ($p< 0.05$).

3.2. Pollution assessment

The pollution index (Table 7) and geo-accumulation index in dust samples were calculated with reference from WHO and South African standards. From the indoor dust samples collected from the houses, the pollution index revealed that there was negligible pollution by Zn, Ni and Cu concentrations, but a 'slight pollution' was noticed with Cd and As concentrations. In the

Table 6. Correlation coefficient matrix of trace metals in outdoor dust samples collected from a mining area in Brits.

	Fe Outdoor	Mg Outdoor	Mn Outdoor	Cr Outdoor	Zn Outdoor	As Outdoor	Ni Outdoor	Hg Outdoor	Cd Outdoor	Cu Outdoor
Fe Outdoor	1	0.67**	0.75**	0.90**	0.04	0.62**	0.90**	0.35*	0.65**	0.54**
Mg Outdoor	.67**	1	0.82**	0.67**	0.42**	0.85**	0.80**	0.64**	0.82**	0.75**
Mn Outdoor	0.75**	0.82**	1	0.74**	0.36*	0.72**	0.90**	0.42**	0.76**	0.65**
Cr Outdoor	0.90**	0.67**	0.74**	1	0.05	0.57**	0.90**	0.41**	0.58**	0.56**
Zn Outdoor	0.04	0.42**	0.36*	0.05	1	0.37*	0.18	0.49**	0.44**	0.46**
As Outdoor	0.62**	0.85**	0.72**	0.57**	0.37*	1	0.69**	0.71**	0.92**	0.79**
Ni Outdoor	0.90**	0.80**	0.90**	0.90**	0.18	0.69**	1	0.44**	0.76**	0.69**
Hg Outdoor	0.35*	0.64**	0.42**	0.41**	0.49**	0.71**	0.44**	1	0.65**	0.73*
Cd Outdoor	0.65**	0.82**	0.76**	0.58**	0.44**	0.92**	0.76**	0.65**	1	0.78**
Cu Outdoor	0.54**	0.75**	0.65**	0.56**	0.46**	0.79**	0.69**	0.73*	0.78**	1

$p < 0.01$ (**); $p < 0.05$ (*)

Table 7. Pollution Index for indoor and outdoor dust samples collected from houses around a mining site.

Trace metal		Zn	Ni	Cu	Cr	Cd	As
INDOOR	WHO Standards	0.10	0.13	0.03	0.36	1.44	0.96
	South African Standards	0.12	0.07	0.21	5.59	0.58	3.30
OUTDOOR	WHO Standards	0.04	0.09	0.02	0.25	1.36	0.78
	South African Standards	2.27	0.05	0.15	3.80	0.54	2.68

outdoor dust samples there was a slight pollution observed with Cd and As, which was similar to the indoor dust samples. However, there was a medium to heavy pollution observed with Zn and Cr in the outdoor dust samples.

The calculated Igeo for dust samples from the household showed a value, $0 < Igeo < 1$ for trace metals Zn, Ni, Cu, Cr and Cd, which implies that the study site is unpolluted to moderately polluted. However, the mean concentration of Cr (36.34 ± 23.00 μg/g) indoors and Cr (24.72 ± 14.76 μg/g) outdoors was higher than the geo-chemical background value reported by [13, 52] which was 6.5 μg/g for Cr in South Africa (Table 4). Furthermore, when the mean concentration of Fe, Cr and Ni for the present study was compared to the geo – chemical background value [50] the mean concentrations in the study sites were higher, indicating anthropogenic sources, which may be due to mining activities in the area. The mean concentration for Zn was slightly close to the geo – chemical background value, which also indicate anthropogenic sources [50, 52, 53].

3.3. Health risk assessment

The Hg, Cr and As concentrations for both indoor and outdoor dust samples exceeded the

Table 8. Non-carcinogenic risk assessment for adults exposed to dust particles from a mining area (mg/kg/day).

Receptor pathway		Average Daily Intake (ADI) values of trace metals in mg/kg/day									
		Zn	**Ni**	**Cu**	**Mn**	**Mg**	**Hg**	**Fe**	**Cr**	**Cd**	**As**
INDOOR	ADI_{Inh}	6.04E-9	1.24E-9	6.73E-10	7.63E-9	7.44E-8	8.87E-10	1.75E-7	7.15E-9	8.51E-10	3.77E-9
	HQ	_	_	_	_	_	1.03E-8	_	0.00	1.44E-5	1.26E-13
	ADI_{Ing}	6.49E-9	1.33E-9	7.21E-10	8.17E-9	7.97E-8	9.50E-10	1.90E-7	7.66E-9	9.13E-10	4.04E-09
	HQ	2.06E-8	6.65E-8	1.95E-8	_	_	3.17E-6	_	2.55E-6	0.00	1.354-5
	ADI_{Der}	9.75E-7	2.00E-7	1.08E-7	1.22E-6	1.20E-5	1.43E-7	2.86E-5	1.15E-6	1.37E-7	6.07E-9
	HQ	0.00	3.57E-5	0.00	_	_	0.00	_	_	0.00	2.02E-5
OUTDOOR	ADI_{Inh}	2.56E-9	9.30E-10	4.78E-10	4.48E-9	5.57E-8	7.40E-10	1.72E-7	4.86E-9	8.00E-10	3.06E-9
	HQ	_	_	_	_	_	8.60E-9	_	0.00	1.40E-5	0.00
	ADI_{Ing}	2.77E-9	9.86E-10	5.12E-10	5.18E-9	5.86E-8	7.86E-10	1.85E-7	5.21E-9	8.58E-10	3.32E-9
	HQ	9.23E-9	1.97E-11	1.38E-8	_	_	0.00	_	1.74E-6	0.00	9.96E-10
	ADI_{Der}	4.16E-7	1.48E-7	7.69E-8	7.79E-7	8.81E-6	1.18E-7	2.27E-5	7.82E-7	1.29E-9	4.93E-9
	HQ	0.00	2.64E-5	3.20E-6	_	_	0.00	_	_	0.00	1.64E-5

Table 9. Carcinogenic risk assessment for adults exposed to dust particles from a mining area (mg/kg/day).

Receptor pathway		Average Daily Intake (ADI) values of trace metals in mg/kg/day									
		Zn	**Ni**	**Cu**	**Mn**	**Mg**	**Hg**	**Fe**	**Cr**	**Cd**	**As**
INDOOR	ADI_{Inh}	8.65E-10	1.78E-10	9.61E-11	1.09E-9	1.06E-8	1.27E-10	2.54E-8	1.02E-9	1.22E-10	5.38E-10
	$Risk_{pathway}$	_	_	_	_	_	_	_	4.18E-8	1.83E-9	8.07E-9
	ADI_{Ing}	9.02E-10	1.85E-10	1.00E-10	1.14E-9	1.11E-8	1.30E-10	2.64E-10	1.06E-9	1.27E-10	5.61E-10
	$Risk_{pathway}$	_	_	_	_	_	_	_	_	_	8.41E-10
	ADI_{Der}	1.39E-7	2.86E-8	1.55E-8	1.756-7	1.71E-6	2.04E-8	4.08E-6	1.69E-7	2.00E-8	8.67E-8
	$Risk_{pathway}$	_	_	_	_	_	_	_	_	_	0
OUTDOOR	ADI_{Inh}	3.69E-10	1.32E-10	6.83E-11	6.91E-10	7.81E-9	1.05E-10	2.46E-8	6.95E-10	1.16E-7	4.38E-10
	$Risk_{pathway}$	_	_	_	_	_	_	_	2.85E-8	0	1.84E-11
	ADI_{Ing}	3.85E-10	1.37E-10	7.11E-11	7.02E-10	8.15E-9	1.09E-10	2.57E-8	7.24E-10	1.19E-10	4.56E-10
	$Risk_{pathway}$	_	_	_	_	_	_	_	_	_	6.84E-10
	ADI_{Der}	5.95E-8	2.11E-8	1.10E-8	1.11E-7	1.26E-6	1.69E-8	3.96E-6	1.12E-7	1.84E-8	7.04E-8
	$Risk_{pathway}$	_	_	_	_	_	_	_	_	_	0

permissible limit set by South Africa for human exposure to dust samples (Table 3 and 4). The results further showed that Cd from both indoor and outdoor dust samples also exceeded the permissible limit set by WHO for human exposure. However, the assessment of carcinogenic risk, a value between 1E-06 and 1E-04 indicated an acceptable risk of carcinogenesis; 1E-04 indicates a high carcinogenic risk environment, and 1E-06 represented a precautionary criterion, while, an HQ value for non-carcinogenic risk ≥ 1 indicates potential risk for humans. Tables 8 and 9 shows the health risk assessments including inhalation, ingestion and dermal exposure analysis for household (indoor and outdoor) dust samples collected from the mining area in Brits. The assessment observed the adverse health risk effects of airborne metal exposure.

The non-carcinogenic and carcinogenic risks of trace metals for individuals were calculated according to the parameters in Table 1. The risks were calculated for adults through the different pathways which include inhalation, ingestion and dermal exposure in dust samples. For non-carcinogenic risk, the HQ value was less than 1 for all exposure pathways in indoor and outdoor dust samples (Table 8). The results at this stage indicate that there was no non-carcinogenic risk for humans, either through inhalation, ingestion or dermal exposure to indoor and outdoor dust.

The results of the cancer risk evaluation showed the value of 1.83×10^{-9} for Cd (indoor) and 1.84×10^{-11} for As (outdoor) from inhalation pathway. The recorded values may not indicate a high carcinogenic risk; however, they are close to the 1E-06 value, which represents a precautionary criterion for carcinogenic risk. For ingestion and dermal pathways, there was no carcinogenic risk observed for human exposure to trace metals Cr, As and Cd as calculated in Table 9. Furthermore, it has been observed that the concentrations of trace metals Hg, Cr, As and Cd have exceeded the permissible limit set by WHO and South Africa, as a result of the bioaccumulation nature of trace metals in the body; there may be a potential non-carcinogenic and carcinogenic risk to humans in the future.

From the results, the values recorded for dust samples containing Fe, Hg, Mg, Cr, Cu, Mn, Ni, As, and Zn were lower than the safety limit for adults as prescribed in the precautionary criterion of 1E-06, indicating that the amount of trace metals contained in the dust samples at this stage was not enough to cause carcinogenic and non - carcinogenic risk. The results of this study were similar to the findings of [54] which showed the HQ for Cd and Hg to be within the safety limit.

4. CONCLUSION

The study showed that human exposure to trace metals through different pathways such as inhalation, ingestion and dermal exposure may have an impact on their general health especially when they are living around mining activities. From the results of the current study it can be concluded that exposure to mining activity may pose a threat to human health owing to the levels of some metals such as Hg, Cr, As and Cd that were reported to be above the permissible limit. However, the exposure to trace metals found in dust samples from the mining area may be as a result of multiple pathways, which also include inhalation, ingestion and dermal exposure. Though the health risk assessment indicated that there might be no risk posed to individuals living around the study site at this stage there is a cause for concern, since trace metals Fe, Mg, Cu, Hg, Cr, As and Cd in some households exceeded the permissible limit, which may be harmful for human exposure. There is a possible future concern for human health, especial due to the fact that trace metals tend to bio-accumulate and cause toxicity. Furthermore, there is a need for continuous monitoring of trace metal pollution in this area.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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