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HEALTH RISK ASSESSMENTS OF HEAVY METALS IN KAOLIN DUST FROM A KAOLIN MILLING PLANT IN ALKALERI, BAUCHI STATE, NIGERIA

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Abstract: This study concerns the health risk assessments of Kaolin dust from a Kaolin milling plant in Alkaleri, Bauchi State. The aim is to determine the concentration of elements and the health risk assessments of heavy metals in the Kaolin dust from a Kaolin milling plant. The Kaolin dust samples were collected in the milling plant by spreading a plastic sheet on a surface of about 2 m above the ground level. The elemental analysis of the Kaolin dust was carried out using Neutron Activation Analysis (NAA). Pb and Zn were determined using atomic Absorption Spectrophotometer after digestion with mixture of HCl and HNO_3 in 1:3 ratios. The results showed the concentration of heavy metals were As = BDL, Cd = BDL, Cr = 99.1±7.3, Co = 6.46±0.8, Cu = 266±0, Mn= 66.6± 4.3, Pb = 15.33±1.0, V= 43.6±10.6, and Zn = 3.5±0. The health risk assessment was carried out using the method developed by the United States Environmental Protection Agency. The health risk assessment showed the daily exposure doses of metals are in the order of Cu > Cr > Mn > Pb, V> Co > As, Cd, the exposure pathways showed the trend, Ingestion > dermal > inhalation. The Hazard Index (HI) of all heavy metals Kaolin dust for non-carcinogenic effect of metals in the Kaolin dust is in the order Cr > Co > Pb > V > Cu > Mn > Zn, the HIt is far less than 1 which is the safe value. The cancer risk index for carcinogenic effect of metals in Kaolin dust is in the order Cr > Co and also within the safe value of $10^{-6} – 10^{-4}$. These indicate that the Kaolin dust samples analyzed do not pose major adverse health effect.

Keywords: Kaolin, NAA, AAS, health risk, carcinogenic, non-carcinogenic, cancer risk

Introduction

Some metals constitute an important class of toxic substances which are encountered in numerous occupational and environmental circumstances. The impact of these toxic agents on human health is currently an area of intense interest due to the ubiquity of exposure (Sharma, 2010). Soils may be contaminated by the accumulation of heavy metals and metalloids through emissions from the rapidly growing industrial areas, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilizers, animal manures, sewage sludge, pesticides and atmospheric deposition (Khan *et al.,* 2008). Heavy metals such as As, Cd, Hg, Se, Pb, and Zn are presented as strongly hazardous elements, whereas Co, Ni, Mo, Sb, and Cr as moderately hazardous in the general toxicological Russian GOST (State Norms and Standards) (Vodyanitskii, 2016).

Kaolin a white, claylike material composed mainly of kaolinite, which is a hydrated aluminum silicate ($Al_2O_3·2SiO_2·2H_2O$), and other kaolin-group minerals. Kaolin has a wide variety of industrial applications including paper coating and filling, refractory, fiberglass and insulation, rubber, paint, ceramics, and chemicals. Kaolin mining and refining involve considerable exposure and significant exposure is expected in paper, rubber and plastics production. Kaolin contains quartz and exposure to quartz is casually related to silicosis and lung cancer. Significant increases in the incidence of mortality from chronic bronchitis and pulmonary emphysema have been reported after exposure to quartz (Toxnet, 2013). Kaolin is rated low in hazard to humans, pets, and wildlife from potential exposures (USEPA, 2000). No report on local or systemic adverse effects has been identified from the extensive use of bentonite or kaolin in cosmetics (IPCS INCHEM, 2005). This study is therefore aimed at determining the concentration of elements and the health risk assessments of heavy metals in the Kaolin dust from a Kaolin milling plant.

Material and Methods

Samples collection

Samples of Kaolin dust were collected inside the milling plant (Fig. 1) with the aid of a plastic sheets spread on a surface of about 2 m above the ground. The settled dusts on the sheets were scooped into a small plastic reclosable bag with a brush and labeled.

Sample preparation for NAA analysis

The method described by Jonah *et al.* (2006) with some modification was adopted. This consists primarily of weighing and packaging of samples and wrapped in polyethylene bags. Before weighing the samples, the polyethylene bags and rabbit capsules were cleaned by soaking in 1:1 HNO_3 (Nitric acid) for 3 days and washed with de-ionized water to sterilize and oven dried. The dust samples were weighed with a four-digit Melter model weighing balance in the range of 150 to 200 mg encapsulated, heat sealed in a polyethylene material and package finally into a polyethylene vial as adopted for NIRR-1 at Centre for Energy Research and Training ABU, Zaria.

Sample Irradiation

The protocols for sample irradiation were performed in two irradiations stages as described by Jonah *et al.* (2006), Oladipo *et al.* (2012). Arrangements of elements with short life are determined using the short live protocol. Samples packaged in the vials are sent to the reactor irradiation sites using the rabbit system (pneumatic transfer system) at a time and the neutron flux was determined by theoretical expression based on estimated activity of the sample (Jonah *et al*., 2006).

Standard reference material IAEA Soil-7 and Coal Fly Ash SRM (1633STTD) were analyzed along with the samples for method substantiation and quality control purposes. From results obtained, it was observed that most of the elemental concentrations are comparable to the certified values.

Sample preparation for AAS

USEPA (1996) method 3050B was adopted with some modification. 1.0 g of the soil samples were weighed in a beaker and digested with 50 cm^3 of mixture HCl and HNO_3 in 3:1 ratio (Aquaregia). The mixture was heated at 95°C for 3 h and then filtered into a 50 ml volumetric flask through acid washed filter paper (Whatmann 24) And made up to the mark with distilled water. The sample blank was prepared which is the mixture of the acid and distilled water without the Sample.

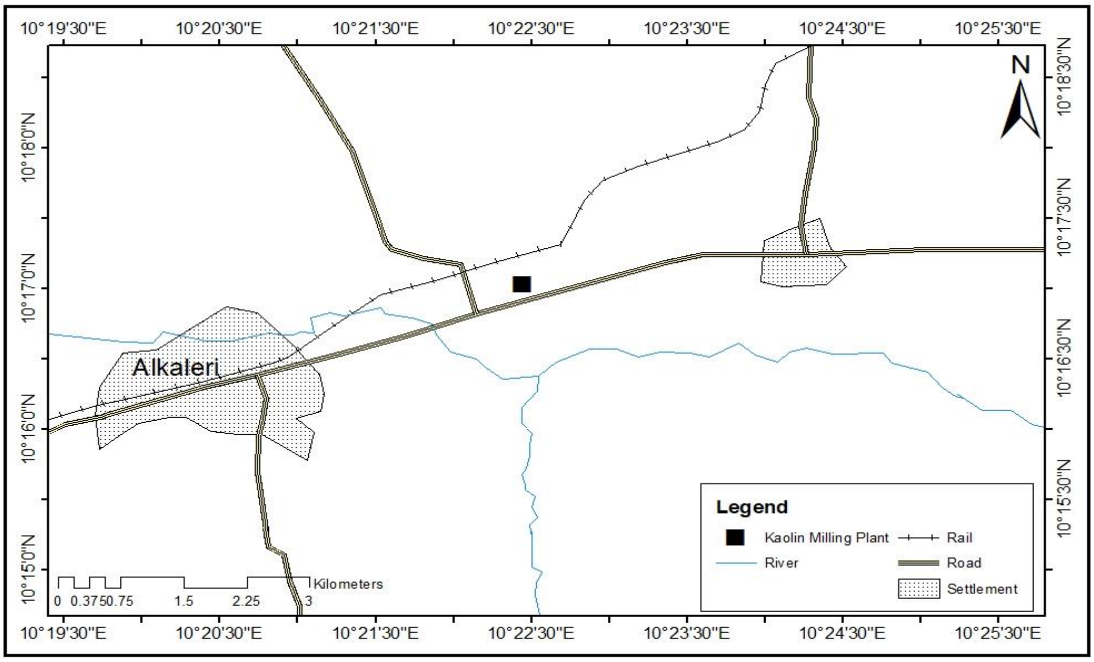

Fig. 1: Map of Alkaleri showing the sample location

Elemental analysis

The concentrations of zinc and lead in the digested Kaolin dust samples were determined by atomic absorption spectrophotometer (Buck scientific model V G P) using air – acetylene mixture at wavelength of 220.350 nm for Pb and 213.855 nm for Zn. The calibration curves were prepared from standard solutions of respective elements.

Risk assessment method

Health risk assessment model

Health risk assessment for non-carcinogenic and carcinogenic risk assessment via three exposure pathways: ingestion, dermal contact, and inhalation, has been recognized as an important tool for identifying health risk in human activities and providing risk evidence for decision-makers (Hu *et al*., 2016; Hu *et al*., 2017). Health risk assessment model used in this study is based on the method developed by the United States Environmental Protection Agency (USEPA, 1989). The daily intake doses of heavy metals in soil and dust are usually through three main paths namely ingestion, inhalation and dermal contact can be calculated using the following equations.

Ingestion

AD_{Ing} (mg.Kg^{-1}day^{-1}) = $\frac{CS \times IR_{ing} \times EF \times FI \times ED \times CF}{BW \times AT}$ (USEPA, 1989)

Inhalation

AD_{Inh} (mg/Kg^{-1}day^{-1}) = $\frac{CS \times IR_{inh} \times EF \times FI \times ED}{PEF \times BW \times AT}$ (USEPA, 1989)

Dermal

AD_{Der} (mg.Kg^{-1}day^{-1}) = $\frac{CS \times SA \times AF \times ABS \times EF \times ED \times CF}{BW \times AT}$ (USEPA, 1989)

Where AD (mg.Kg^{-1}.day^{-1}) is the absorbed dose of exposure to metals through ingestion (AD_{Ing}), inhalation (AD_{Inh}) and dermal contact (AD_{Der})

CS = Chemical concentration in soil (mg/Kg) (This study)

IR_{ing}= Ingestion rate (mg soil/day): 100 mg/day (USEPA, 2011; Liu *et al.,* 2013).

IR_{inh} = Inhalation rate m^3/h: 20 m^3/h for adult (EPA 1989; USEPA, 1989).

FI = Fraction ingested from contaminated Source: 1 at reasonable maximum exposure (USEPA, 2001).

EF = Exposure frequency: 350 days a year (USEPA, 2011; Liu *et al.,* 2013).

ED = Exposure duration (years): 30 years for non carcinogenic effect (USEPA, 2011; Liu *et al.*, 2013).

SA = Exposure skin area: 5700 cm^2 (USEPA, 2011; Liu *et al.,* 2013).

AF = Soil to skin adherence factor (mg/cm^2): 0.07 mg/cm^2 (USEPA, 2011; Liu *et al.,* 2013).

ABS = Absorption factor: 0.03 (As) 0.001 (other metals) (USEPA, 2011; Liu *et al.,* 2013).

BW = Body weight (Kg): 70 Kg for adult average (EPA 1989; USEPA, 1989).

PEF = Particle emission factor: 1.36 × 10 ^{9} m^3.Kg^{-1} (USEPA, 2002; Liu *et al.,* 2013).

AT = Averaging time: 365 × ED for non carcinogenic effect and 365 × 70 for carcinogenic effect (USEPA, 2011; Liu *et al.,* 2013).

CF = Conversion factor (10^{-6}).

Hazard quotient

The hazard quotient (HQ) represents the potential non-carcinogenic risk for an individual heavy metal. The HQ is defined as the ratio of CDI (mg/kg/day) to the reference dose (RfD, mg/kg/day) and is an estimation of daily exposure to the human population that is not likely to represent an appreciable risk of deleterious effects during a lifetime (USEPA, 2010; Hu *et al.,* 2017).

$$HQ = \frac{AD}{RfD}$$

The RfD_{ing} (mg.Kg^{-1}.day^{-1}) of heavy metals in this study are as follows, Cd = 1.00 × 10^{-3}, Cr = 3.00 × 10^{-3}, Co = 3.00 × 10^{-4}, Cu = 4.00 × 10^{-2}, Pb = 3.50 × 10^{-3}, V = 5.04 × 10^{-3} and Zn = 3.00 × 10^{-1} (Zheng *et al.*,2015). Mn = 1.40 × 10^{-1} and As = 3.00 × 10^{-4} (Bortey-Sam *et al.,* 2015).

The RfD_{inh} (mg.Kg^{-1}.day^{-1}) of heavy metals in this study are Cd = 1.00 × 10^{-3}, Cr = 2.86×10^{-5}, Co = 5.71 × 10^{-6}, Cu = 4.02 × 10^{-2}, Pb = 3.52 × 10^{-3}, V = 7.00 × 10^{-3} and Zn = 3.00 × 10^{-1} (Zheng *et al.,* 2015). Mn = 1.43 × 10^{-5} (Boney-Sam *et al.,* 2015) and As = 3.00 × 10^{-4} (Li *et al.,* 2013).

The RfD_{der} (mg.Kg^{-1}.day^{-1}) of heavy metals in this study are Cd = 1.00 × 10^{-5}, Cr = 6.00 × 10^{-5}, Co = 1.60 × 10^{-2}, Cu = 1.20 × 10^{-2}, Pb = 5.25 × 10^{-4}, V = 7.00 × 10^{-5} and Zn = 6.00 × 10^{-2} (Zheng *et al.*,2015). Mn = 1.84 × 10^{-3} and As = 1.23 × 10^{-4} (Li *et al.,* 2013).

Hazard index

Hazard Index (HI) indicates the potential non-carcinogenic risk post by more than one metal. Total Hazard Index (Hit = HI_{ing}+ HI_{inh}+ HI_{der}) refers to the sum of more than one HI for multiple pathways.

$HI = \sum HQ_i$, where i corresponds to different heavy meals. HI ≤ 1 indicated no adverse health effects and HI > 1 indicated likely adverse health effects (Guney *et al.*, 2010; Zheng *et al.*, 2010; Li *et al.*, 2013).

The carcinogenic health risk (RI) assessment is calculated by multiplying the daily exposure dose by the corresponding slope factor (SF) to produce an estimate of cancer risk (Zheng *et al.*, 2010b; Kong *et al.*, 2012; Li *et al.*, 2013). Slope factors (SF) inhalation in mg/Kg day^{-1}of Cd = 6.30, As = 15.1 (Li *et al.*, 2013), Co = 9.80, Cr = 41 (Zheng *et al.*, 2015). Slope factor (SF) ingestion of As = 1.5 mg/Kg day^{-1} (Bortey-Sam *et al.*, 2015). The acceptable or tolerable cancer risk for regulatory purposes is in the range between 10^{-6} – 10^{-4} (USEPA, 2001, Liu *et al.*, 2013).

Result and Discussion

Table 1 shows the concentration and health risks from heavy metal in Kaolin dust. The daily exposure level of As, Cd, Co, Cu, Mn, Pb, V and Zn were determined through three (3) different pathways, Ingestion, inhalation and dermal. The metals daily exposure doses in Kaolin sample are in the order Cu > Cr > Mn > Pb, V> Co > As, Cd. The exposure pathways showed the trend decreases in the order Ingestion > dermal > inhalation. The ingestion pathway is the dominant route for all the metals. Ingestion pathway being the dominant route for daily exposure doses is in agreement with the study conducted by Zheng *et al.* (2015) and Han *et al.* (2017) the trend is also similar to the one reported by Zheng *et al.* (2015).

Table 1: Concentration (mg/Kg) and Health risks from heavy metal in Kaolin dust from the vicinity of a Kaolin milling Plant (mg.Kg-1.day-1)

Metals	Concentration in mg/Kg	ADing	ADinh	ADinh**	ADder	HQing	HQinh	HQder	HIt	RI
As	BDL	-	-	-	-	-	-	-	-	-
Cd	BDL	-	-	-	-	-	-	-	-	-
Cr	99.1±7.3	1.36E-04	2.00E-08	8.55E-09	5.42E-07	4.52E-02	6.98E-04	9.03E-03	5.50E-02	3.51E-07
Co	6.46±0.8	8.85E-06	1.30E-09	5.57E-10	3.53E-08	2.95E-02	2.28E-04	2.21E-06	2.97E-02	5.46E-09
Cu	266±0	3.64E-04	5.36E-08		1.46E-06	9.11E-03	1.33E-06	1.21E-04	9.23E-03	
Mn	66.6±4.3	9.12E-05	1.34E-08		3.64E-07	6.52E-04	9.38E-04	1.98E-04	1.79E-03	
Pb	15.33±1	5.93E-05	8.72E-09		2.37E-07	1.69E-02	2.48E-06	4.51E-03	2.15E-02	
V	43.6±10.6	5.93E-05	8.72E-09		2.37E-07	1.18E-02	1.25E-06	3.38E-03	1.52E-02	
Zn	3.5±0	4.79E-06	7.05E-10		1.91E-08	1.60E-05	2.35E-09	3.19E-07	1.63E-05	
							HI			
						1.13E-01	1.87E-03	1.73E-02	1.32E-01	

The following Figures (Figs. 2 – 6) showed the concentration and health risk assessment of heavy metals in Kaolin dust from the milling plant.

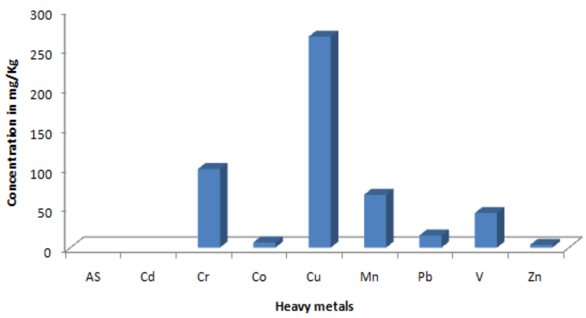

Fig. 2: Distribution of heavy metals in Kaolin dust from Kaolin milling plant

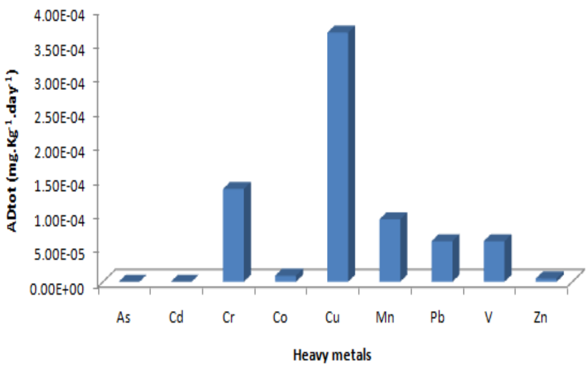

Fig. 3: Average daily exposure doses of heavy metal in Kaolin dust from the Kaolin milling Plant (mg.Kg^{-1}.day^{-1})

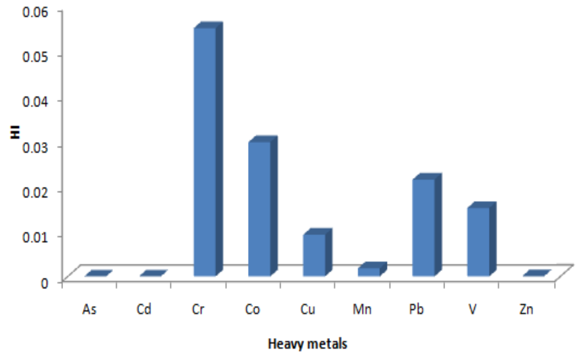

Fig. 4: Hazard Index of non carcinogenic heavy metals in Kaolin dust from the Kaolin milling Plant

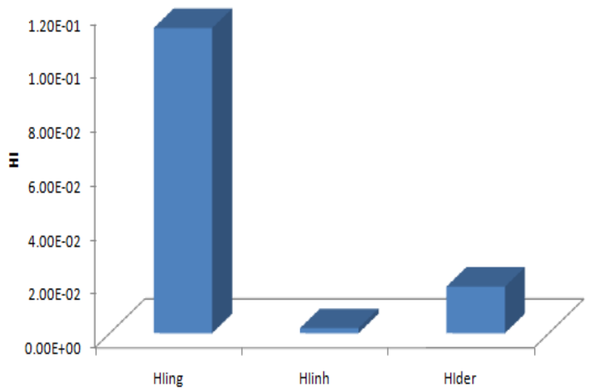

Fig. 5: Hazard Index of Kaolin samples from different pathways from the vicinity of a Kaolin milling Plant

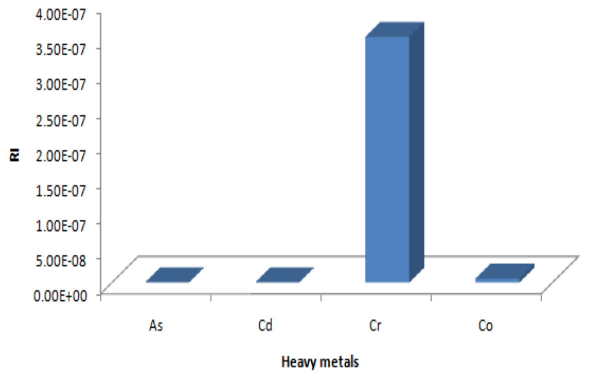

Fig. 6: Mean carcinogenic risk (RI) of metals in Kaolin samples from the vicinity of a Kaolin milling Plant

The Hazard quotient (HQ) values of all the metals through different pathways for kaolin dust is in the order ingestion > dermal > inhalation except Co and Mn. The pathway exhibited by Co is in the order Ingestion > inhalation > dermal and Mn pathway is inhalation > ingestion > dermal. The ingestion pathway is the dominant route for heavy metals health effect except Mn whose dominant route is inhalation. The HQ of metals in the Kaolin sample shows Cr (4.52×10^{-2}) with the highest HQ in the ingestion route and Zn (1.60×10^{-5}) as the lowest value of HQ. The highest HQ in the inhalation route was Mn (9.38×10^{-4}) and the lowest value was in Zn (2.35×10^{-9}). The highest HQ for dermal route was seen in Cr (9.03×10^{-3}) and the lowest HQ was in Zn (3.19×10^{-7}).

The total health risk for the three exposure route (HIt) for all the analyzed metals are far below the safe level of 1. The HIt for metals in the Kaolin dust sample are in the order Cr > Co > Pb > V > Cu > Mn > Zn. The mean value of HIt for Cr is 5.50×10^{-2}, minimum value is 5.09×10^{-2} and maximum value is 5.90×10^{-2}. These values are far less than 1 indicating that the Kaolin dust sample does not pose major non carcinogenic adverse health effect.

The cancer risk index (RI) of the metals in the Kaolin dust sample is in the order Cr > Co. The RI value of Cr (8.19×10^{-7}) is the highest and that of Co (1.28×10^{-8}) is the lowest. The mean total cancer risk index through the inhalation route is 8.31×10^{-7}, minimum value is 7.70×10^{-7} and the maximum is 8.93×10^{-7}. These values are within the acceptable or tolerable cancer risk value of 10^{-6} – 10^{-4} indicating a very low carcinogenic risk in Kaolin dust.

Conclusion

The daily exposure level of heavy metal for non-carcinogenic and carcinogenic effect in Kaolin dust sample is in the order Cu > Cr > Mn > Pb, V > Co >As , Cd for the three exposure pathways which follow the trend in the decreasing order of ingestion > dermal > inhalation. The total hazard index (HI) for the metal for all the three pathways in kaolin dust sample is in the order Cr > Co > Pb >V > Cu > Mn > Zn. The cancer risk index of heavy metal is in the order Cr > Co. The health risks assessments showed the health risks indices for non carcinogenic and carcinogenic effects of heavy metals in the Kaolin dust samples were within safe limits. The ingestion pathway is the dominant pathway for the non carcinogenic effect of heavy metals in Kaolin dust.

Conflict of Interest

Authors declare that there is no conflict of interest.

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