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Health risk assessment of heavy metal exposure from occupational dust in ashaka cement factory of north-eastern Nigeria

[*1] BM Wufem, [2] HM Maina, [3] ON Maitera, [4] PM Dass
[1] Chemistry Department, Plateau State University Bokkos, PMB, Jos, Nigeria
[2, 3, 4] Chemistry Department, Modibbo, Adama University of Technology Yola, Nigeria

Abstract
Potential health risk of cement factory occupational dust was assessed by calculating the daily exposure doses and subsequently determining the hazard index for the carcinogenic and non-carcinogenic metals. Cement Factory Dust (CFD) and Kiln Feed Dust (KFD) exposure doses for three intake routes showed similar trends for As, Cr, Co, V, Zn, and Mn with dermal route being the dominant pathway of intake with the trend decreasing in the order Dermal > Ingestion > Inhalation. Highest mean exposure dose in CFD was $1.102x10^4$ $mgKg^{-1}day^{-1}$ Mn and the lowest mean exposure dose was $376.720x10^{-8}$ $mgKg^{-1}day^{-1}$ As for the dermal route. KFD showed highest dermal dose of $6.253x10^2$ $mgKg^{-1}day^{-1}$ for Fe and a lowest dermal dose of $1.100x10^{-2}$ $mgKg^{-1}day^{-1}$ for Hg and Sb. The dermal route constitutes over 99% of the metal intake for each metal in the CFD and KFD. The hazard quotients for the non-cancer toxic risk indicated higher health risk in the dermal route for all the metals in the two dust types. The dermal routes had HI > 1, which suggests likely adverse health effect for all the metals that routed through the skin and eyes. Carcinogenic effects showed As intake through dermal pathway to have highest carcinogenic risk while inhalation presents the lowest risk in both cement factory and Kiln feed dusts. Cr posed lesser cancer risk to occupational staff as its highest risk index was $9.307\ x10^{-10}$ and it's lowest was $1.997\ x10^{-11}$. On the basis of dermal pathway being the most susceptible routes through which there might be chance of non-carcinogenic and carcinogenic effects, we therefore recommend protective measures that will reduce dust having contact with skin and eyes of occupational staff.

Keywords: health risk, heavy metals, cement dust, kiln feed dust, occupational dust

1. Introduction

Over the years the potential health risk of inhaling dust has been a source of concern to most researchers and this has become an issue because of heavy metal enrichment in the environment due to human land use activities. Recently, much attention has been turned to the assessment of human health risk due to heavy metals exposure from dusts [1, 2. 3]. This is because of the toxic nature of heavy metals and the threats they pose to human life [4]. Heavy metal can be from sources such as Vehicular emissions, industrial discharges, agricultural activities, etc [5, 6, 7]. These sources deposit chemical contaminants on soils which serve as sink and any soil perturbation may bring about raising of tiny soil particles in the form of dusts. As such excess accumulation of heavy metals potent serious health risks to humans and the ecosystem [8, 9].

An industrial production in which high dust is generated exposes workers to high occupational dusts of 59 – 95 mg/m^3 and 20 – 23 mg/m^3 respiratory dust exposures [10, 11]. Cement industry is one of such industries that produce large volume of dust and its workers may be exposed to dust at various manufacturing and production process steps and the exposure limits may be exceeded in most developing countries [12, 13]. Thus, dust is a major hazard in cement production as human exposure to chemical particles can provoke serious health effect. The route of exposure of dust to humans is through inhalation, ingestion, and eye or skin contact [14]. The aerodynamic diameter of cement dust particles is within the respirable extent [15] as to cause numerous occupational health hazards and the health risks posed by inhaled dust particles could be influenced by the duration of exposure and the biological responses exerted by the particles [16]. Various reports exist in the literature on the environmental health risks of heavy metals in dusts. For instance the concentrations of carcinogenic risk substances of cadmium (Cd), chromium (Cr), arsenic (As) as well as non-carcinogenic risk substances of lead (Pb), mercury (Hg), copper (Cu), zinc (Zn), ammonia (NH3-N) and nitrate (NO3--N) and the human health risk by water consumption were determined by Yang and Liu [1]. Abbasi and Tufail, [17] also reported the health risk assessments for non-carcinogenic and carcinogenic effects due to the heavy elements in suspended dusts trapped in Air conditioner filters for both children and adults. Similarly the Accumulation and risk assessment of heavy metals in dust in main living areas of Guiyang City, Southwest China and the concentrations and ecological health risks of metals in the re-suspended particles of urban street dust collected from an industrial city, Baotou, China were studied by Xu, [18] and Li, *et al*. [19] respectively. Heavy metal contamination and human health risk were the point of concern in the investigation of soil dust at a fuel filling station [3]. Zheng *et al* [20]. reported the spatial distribution, pollution level and potential health risk of heavy metals where they were analyzed by Geographic Information System (GIS) mapping technology, geoaccumulation index and health risk assessment model. However, most studies on cement dust exposure dwelled on the effect on respiratory system, liver function, dermatological, hematological and cytological damage [21, 22. 23]. Scanty work [24] has been done on the risk assessment of cement dust. This work was based on a previous research work by Wufem *et al*. [25] which reported that Ashaka cement factory dust was contaminated with As, Mn, Cr and Fe while the Kiln Feed dust was contaminated with Hg, As, Mn and Sb. Health risk assessment is considered useful as it provides information to factory workers and managers on how to protect or minimize risk of staff to occupational hazardous chemicals. It also helps to cut down the presence of such chemicals in raw materials, fuel, and other sources. It is on this background that this work was carried out with the aim of determining the health risk of heavy metal exposures from occupational dust for Cement factory workers.

2. Materials and Methods

Sample Collection and Pre-treatment

Cement dust was scraped from surfaces at different sites inside the factory using paper according to Wufem *et al* [26]. Collected samples were stored inside polythene bags. Kiln Feed was also collected from surfaces at the raw material introduction point in the calcinations chamber. Replicate samples, of 100 mg each, were weighed and sealed in polythene bags. Elemental compositions of all samples were determined using Nigerian Research Reactor – 1 (NRR-1) at the Center for Energy Research and Training, Ahmadu Bello University Zaria [26].

Health risk assessment method

The common risk assessment of heavy metals exposure used for dust was the adoption of the methods used on soil [27, 28, 29]. The route of chemical substances transfer from dust surface to human body is by ingestion, dermal absorption and Inhalation. Ingestion can be by hand-to-mouth ingestion, dermal absorption through body hair pores and inhalation through mouth and nose. The chemical dose entering the body by each of these pathways can be calculated using the equations below.

For Daily dose of Inhaled dust particles;

$$Dinh = \frac{C \times IRinh \times F \times EF \times ED}{PEF \times BW \times AT} \qquad [1]$$

For Daily dose of dust Ingested;

$$Dinh = \frac{C \times IRing \times F \times EF \times ED \times CF}{BW \times AT} \qquad [2]$$

For Daily dermal dose of dust;

$$Dinh = \frac{C \times CF \times SA \times AF \times ED \times F \times EF \times ABS}{BW \times AT} \qquad [3]$$

Where, D_{ing} is the daily dose via ingestion of particles; D_{inh} is the daily dose via inhalation of suspended particles; D_{dermal} is the daily dose via dermal absorption particles; and other terms are as defined in table 2.

Table 1: Standard Reference Doses for Heavy metals ($mgKg^{-1}day^{-1}$) and Slope Factors.

Metal	Ref_{Inhal}	Ref_{derm}	Ref_{Ingest}	Sf_{Inhal}	Sf_{derm}	Sf_{Ingest}	References
As	-	1.23E-04	3.00E-04	1.51E-01	3.660	1.51E-01	[3, 17]
Cr	2.86E-05	6.00E-05	3.00E-03	4.10E-01	-	4.20E-01	[3, 17. 20]
Co	5.71E-06	1.60E-02	3.00E-04	9.80	-	-	[3, 20]
V	7.00E-03	7.00E-03	5.04E-03	-	-	-	[3]
Zn	3.00E-01	6.00E-02	3.00E-01	6.37E-09	1.73E-06	4.33E-05	[3, 30]
Mn	1.40E-05	1.80E-03	4.60E-02				[3]
Fe	7.00E-01	7.00E-01	-				[31]
Hg	3.00E-01	-	3.00E-04				[32]
Sb	4.00E-04	-	2.00E-01				[32]

Hazard quotient (HQ) and Hazard Index

The model for Hazard indexes (HIs) for carcinogenic and non-carcinogenic effects were applied on the dust metal concentration [26] for each exposure pathway to determine the daily doses of the metal uptake by occupational staff of Ashaka cement factory. To obtain the non-carcinogenic risk (HQ), the doses calculated for each metal exposure pathway were divided by the corresponding reference dose (RfD). On the other hand, the cancer risk index was obtained by multiplying the carcinogenic metal dose by the corresponding slope factor (SF). The RfD and SF values of all metals analysed in this study are presented in Table 1. Table 2 gives the input parameters for the computation of average daily exposure dose. The overall Hazard index ($HI = \sum HQ$) is the sum of HQ for the individual metals determined for all the intake routes calculated [27, 29, 33]. The result of the HQ and HI Values were interpreted according to USEPA [34], where it suggested that if the value of HQ or HI < 1, it indicates there is no significant risk of non- carcinogenic effects. If HQ or HI > 1, it means there is a chance that non-carcinogenic effects may occur. The total hazard index is the sum of more than one HI for multiple pathways ($H_{It} = H_{Iing} + H_{Iinh} + H_{Ider}$). There is no significant risk of non-carcinogenic effects when these indexes are no more than 1, whereas experiencing adverse health effects is possible when these indexes are more than 1. The acceptable or tolerable risk is in the range of $10^{-6} – 10^{-4}$ for carcinogens [20]. However, Lemly [35] had classified the total hazard index as HIt = 1.1 – 10 to be moderate hazard and >10 as High hazard. Carcinogenic risk is the probability of an individual developing any type of cancer from lifetime exposure to carcinogenic hazards. This is obtained by multiplying the carcinogenic exposure doses by the slope factor to yield the Risk Index (RI). The acceptable or tolerable risk for regulatory purposes is in the range $10^{-6} – 10^{-4}$ [36].

Table 2: Input parameters for the determination of average Doses for Carcinogenic and non-Carcinogenic [20]

Parameter	Definition	Units	Carcinogenic Value	Non-carcinogenic Value
ABS	Absorption Factor	-	0.01	0.01
AF	Adherence Factor	$Mg.cm^2$	0.07	0.07
AT	Average Time	Days	70x365	EDx365
BW	Body Weight	Kg	70	70
CF	Conversion Factor	$Kg.mg^{-1}$	10^{-6}	10^{-6}
ED	Exposure Duration	Years	50	40
EF	Exposure Frequency	$Day.years^{-1}$	250	250
PEF	Particle Emission Factor	$M^3.Kg^{-1}$	$1.36x10^{-9}$	$1.36x10^{-9}$
SA	Exposure Skin Surface Area	$Cm^2.day^{-1}$	4350	4350
IRingest	Ingestion Rate	$Mg.day^{-1}$	100	100
IRinhal.	Inhalation Rate	$M^3.day^{-1}$	20	20

3. Results and Discussion

The results of the potential health risks of cement factory occupational dust exposure as per daily exposure levels are given in tables 3 and 4. These were obtained by calculating the daily exposure doses of the metals for the carcinogenic and non-carcinogenic risks according to equations 1 – 3. The Cement Factory Dust (CFD) exposure doses for the three intake routes showed varying trends for the different individual metals such that there was similarity in the order of exposure for As, Cr, Co, V, Zn, and Mn with dermal routes being the dominant pathway of intake (Table 3). The exposure pathway trend decreases in the order Dermal > Ingestion > Inhalation. The same trend was observed for all the heavy metals in Kiln Feed Dust (Table 3). However, the trend for Fe in CFD differs from that of other metals in the same sample as it showed Dermal > Inhalation > Ingestion. The Highest metal exposure dose in CFD was $1.102x10^4$ ($mgKg^{-1}day^{-1}$) Mn and the lowest dust exposure dose was $376.720x10^{-8}$ ($mgKg^{-1}day^{-1}$) As for the dermal routes. The lowest exposure dose in the dermal routes was higher than the Ingestion and Inhalation routes put together. The KFD showed highest dermal dose of $6.253x10^2$($mgKg^{-1}day^{-1}$) Fe and lowest dermal dose of $1.100x10^{-2}$ ($mgKg^{-1}day^{-1}$) for Hg and Sb. The dermal route constitutes over 99% of the metal intake for each metal in the CFD and KFD. These patterns of heavy metal intake in the two dust types differ from that reported by Du *et al* [37]. and Zheng *et al* [20]. on dusts, as they showed ingestion to be the major pathway for heavy metal intake. Among environmental materials that are primarily of earth's crust origin, such as sediment, soil and dust, dust has been considered the most pervasive and has the most important factor that affect human health and well-being [38]. This is because significant amount of toxic heavy metals had been found in air and dust, especially in industrial areas [39]. Earlier Gupta *et al* [40]. and Chen *et al* [41]. had reported that cement industry is one of the major sources of metals especially Cu, Zn, Pb, Ni, Cd, Hg and As which are generated from the combustion of fossil fuels and processing of raw materials. The risk of dust accumulation on occupation workers in the cement industry suggests the possibility of heavy metal intake. Heavy metals have the ability to accumulate after intake as they are difficult to metabolize [42] and can bind to cellular components such as structural proteins, enzymes and nucleic acids, and interfere with their functions [43]. For instance, Robert and Mari [44] reported that high consumption of Co could lead to abnormal thyroid artery, polycythemia, over reduction of red blood cells and right coronary problems and recently, IARC [45] has classified Cr and As as carcinogenic, and Co as possible carcinogenic as quoted by LOC [46]. These Findings stepped from earlier work by Wufem *et al* [25]. where they attributed contamination of the dust studied by heavy metals, hence the assessment of the potential health risks of these metals.

Table 3: Daily exposure doses of Heavy metals in cement factory dust and Kiln feed dust for non-carcinogenic effect.

Metal	CFD			KFD		
	D_{Inhal} (mg/Kg/day)	D_{derm} (mg/Kg/day)	D_{Ingest} (mg/Kg/day)	D_{Inhal} (mg/Kg/day)	D_{derm} (mg/Kg/day)	D_{Ingest} (mg/Kg/day)
As	0.58E-08	1.638	376.720E-08	4.21E-08	1.192	273.98E-08
Cr	71.34E-08	20.173	4638.09E-08	33.06E-08	9.349	2149.47E-08
Co	12.39E-08	3.502	805.31E-08	8.00E-08	2.261	519.58E-08
V	45.68E-08	12.899	2969.75E-08	29.55E-08	8.356	1,953.77E-08
Zn	40.41E-08	555.834	127,792.10E-08	37.58E-08	10.626	2,443.02E-08
Mn	1,965.53E-08	11,024.457	2,534,608.55E-08	1,547.64E-08	437.659	100,622.38E-08
Fe	38,984.51E-08	11.427	2,627.27E-08	22,113.47E-08	625.348	1,437,710.05E-08
Hg	-	-	-	0.39E-08	0.011	25.44E-08
Sb	-	-	-	$0.391X10^{-8}$	0.011	$25.441X10^{-8}$

The potential health risk of heavy metals was determined from the hazard quotients and the results are shown in table 4 for the non-cancer toxic risk. The result indicated the health risks to be higher in the dermal route for all the metals in the two dust types and the hazard index (HI) trend follows the same pattern observed in the exposure dose. The dermal route had HI > 1, which suggests likely adverse health effect for all the metals that routed through the skin and eyes. The Average daily doses and the hazard quotients for the non-cancer effect of Cr, Zn and As in this study were higher than the cement kiln dust of some Egyptian factories reported by El-Abssawy *et al* [24]. where they found average daily dose range of 4.6x10-

^{5} – $5.9x10^{-5}mgKg^{-1}day^{-1}$ and Hazard quotient (HQ) of 0.2 for Cr, average daily dose of $3.7x10^{-5}$ - $4.9x10^{-5}mgKg^{-1}day^{-1}$ for Zn and 2.00x 10^{-6} $mgKg^{-1}day^{-1}$ for As in the three cement factory dust studied. The Total aggregated hazard index for all the three pathways of intake for individual metals whose HI > 1 in CFD showed a hazard index trend decreasing in the order As > Mn > Zn > Co > V > Fe > Cr which means there is a great chance of non-carcinogenic effects, and the probability increases with the increasing value of HI [34]. The HI trend in the KFD decreases in the order Mn > Cr > As > V > Fe > Zn > Co > Hg > Sb and their values were above the safe levels as such these metals have a high possibility of non-carcinogenic effects. These results imply that factory workers could face potential non-carcinogenic health risks from heavy metals in occupational dust in the cause of their duty in the factory. Sb hazard index (0.25 $x10^{-6}$) falls within the acceptable safe limits of 10^{-6} – 10^{-4} [20] as such it may not pose much threat to occupational staff of the cement factory. Comparing the HI for the two dust types indicated higher hazard index for As, Cr and Fe in KFD than in CFD and Co, V, Mn hazard index were higher in CFD than in KFD.

Arsenic has been classified carcinogenic through Inhalation, Ingestion and dermal intake [46] while Cr has been listed as carcinogenic through inhalation only [27, 46]. For the As the major intake pathway for the CFD and KFD was dermal. Table 5 gives the carcinogenic exposure doses for the two dust types with As showing highest exposure dose of 1.17 $mgKg^{-1}day^{-1}$ and lowest exposure dose of $0.04x10^{-10}$ $mgKg^{-1}day^{-1}$ both in the CFD. Carcinogenic effects were expressed by their cancer potency factor [47] which was applied in the computation of the cancer risk index given in table 6. The Risk index for As shows that the dermal route presents the highest carcinogenic risk while inhalation presents the lowest risk in both cement factory and Kiln feed dusts.

Table 4: Hazard Quotients for non-carcinogenic heavy metals in cement factory dust and Kiln feed dust

Metal	CFD				KFD			
	HQ_{Inhal}	HQ_{derm}	HQ_{Ingest}	HI	HQ_{Inhal}	HQ_{derm}	HQ_{Ingest}	HI
As	-	$0.133x10^{5}$	$1255.733x10^{-5}$	$1.330x10^{5}$	-	$9.691x10^{3}$	$9.133x10^{-5}$	$1.770x10^{3}$
Cr	$24.934x10^{-3}$	$3.362x10^{5}$	$1546x10^{-5}$	$4.0428x10^{-2}$	$1,155.940x10^{-5}$	$1.558x10^{-5}$	$716.490x10^{-5}$	$18.740x10^{3}$
Co	$21.692x10^{-3}$	$2.189x10^{2}$	$201.328x10^{-5}$	$2.191x10^{2}$	$1,400x10^{-5}$	$0.141x10^{3}$	$1731.933x10^{-5}$	$0.141x10^{3}$
V	$0.965x10^{-3}$	$1.842x10^{2}$	$589.236x10^{-5}$	$1.842x10^{2}$	$4.221x10^{-5}$	$1.194x10^{3}$	$38.843x10^{-5}$	$1.194x10^{3}$
Zn	$0.135x10^{-3}$	$92.557x10^{2}$	$425.970x10^{-5}$	$9.256 x10^{2}$	$0.12x10^{-3}$	$0.178x10^{3}$	$8.143x10^{-5}$	$0.178x10^{3}$
Mn	$1,403.950x10^{-3}$	$612.470x10^{2}$	$510.019x10^{-5}$	$6.125x10^{4}$	$11.055 x10^{-5}$	$243.144x10^{3}$	$2,187.443x10^{-5}$	$243.144x10^{3}$
Fe	$0.557 x10^{-3}$	$0.163 x10^{2}$	-	$1.630x10^{1}$	$31.591x10^{-5}$	$0.893x10^{3}$	-	$0.893x10^{3}$
Hg	-	-	-	-	$0.001x10^{-5}$	-	$0.848x10^{-5}$	$8.490 x10^{-6}$
Sb	-	-	-	-	$0.978x10^{-5}$	-	$1.272x10^{-5}$	$0.25 x10^{-6}$

Generally, the cancer risk index for the different intake pathways were lower in the Inhalation and Ingestion routes than the acceptable limit of 10^{-6} – 10^{-4}, higher than the acceptable limits in the dermal pathways. Previous research has demonstrated that intake of As could cause cancer in internal organs (such as liver, kidney, lung, bladder), and can increase the risk for skin cancer [48]. Cr in CFD and KFD poses lesser cancer risk to occupational workers as its highest risk index is 9.307 $x10^{-10}$ and its lowest is 1.997 $x10^{-11}$ and despite this Cr level, high intake could cause liver and kidney problems, genetoxic, and carcinogenic conditions [49]. On the basis of dermal pathway being the most susceptible routes through which there could be chance of carcinogenic effect, we therefore recommend protective measures that will reduced dust load on occupational staff.

Table 5: Average Daily exposure Dose of carcinogenic metals in Cement factory dust and Kiln Feed Dust.

Metal	CFD			KFD		
	D_{Inhal} ($mgKg^{-1}day^{-1}$)	D_{derm} ($mgKg^{-1}day^{-1}$)	D_{Ingest} ($mgKg^{-1}day^{-1}$)	D_{Inhal} ($mgKg^{-1}day^{-1}$)	D_{derm} ($mgKg^{-1}day^{-1}$)	D_{Ingest} ($mgKg^{-1}day^{-1}$)
As	4.00E-12	1.170	2.69E-06	2.90E-10	0.851	1.96 E-06
Cr	4.87E-11	-	-	2.27E-09	-	-

Table 6: carcinogenic Risk Index for Heavy metals in cement factory dust and Kiln feed dust

Metal	CFD			KFD		
	RI_{Inhal}	RI_{Derm}	RI_{Ingest}	RI_{Inhal}	RI_{Derm}	RI_{Ingest}
As	6.04E-11	4.282	4.06E-09	4.38E-11	3.115	2.96E-11
Cr	2.00E-11	-	-	9.31E-10	-	-

4. Conclusion

Result of a previous analysis on Dusts from Ashaka cement factory [20] was fed into health risk models to assess the potential health risk of heavy metals by calculating the daily exposure doses and subsequent determination of hazard index for the carcinogenic and non-carcinogenic metals. Cement Factory Dust (CFD) and Kiln Feed Dust (KFD) exposure doses for the three intake routes showed skin to be the dominant pathway of metal intake with the metals decreasing in the order As > Cr > Co > V, Zn > Mn. The dermal routes constituted over 99% for the entire metal intake in the CFD and KFD. The intake trend decreases in the order Dermal > Ingestion > Inhalation. However, the intake trend for Fe in CFD differs from that of other metals in the same sample as it showed Dermal > Inhalation > Ingestion. Highest exposure dose in CFD was $1.102x10^4$ $mgKg^{-1}day^{-1}$ Mn and the lowest exposure dose was $376.720x10^{-8}$ $mgKg^{-1}day^{-1}$ As for the dermal routes. The hazard quotients for the non-cancer toxic risk indicated higher health risks in dermal pathway for all the metals in the two dust types. The Total hazard index for all the three pathways of intake for individual metals whose HI > 1 in CFD showed a hazard index trend decreasing in the order As > Mn > Zn > Co > V > Fe > Cr, indicating a great chance of non-carcinogenic effects. The HI trend in the KFD decreases in the order Mn > Cr > As > V > Fe > Zn > Co > Hg > Sb and their values were above the safe levels as such these metals have a high possibility of non-carcinogenic effects. Carcinogenic effects were assessed from the cancer risk index and the result showed that As routed through dermal pathway have highest carcinogenic risk to adult workers while inhalation presents the lowest risk in both cement factory and Kiln feed dusts. Cr posed lesser cancer risk to occupational staff as its highest risk index was $9.307\ x10^{-10}$ and its lowest was $1.997\ x10^{-11}$. These results imply that factory workers could face potential non-carcinogenic health risks from the heavy metals and carcinogenic risk due to As in occupational dust in the cause of their duty.

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6. Conflict of interest
The authors declare no conflict of interest

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