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Evaluation of Heavy Metal Contamination Characteristics of Cement Factory and Kiln Feed Dusts in Ashaka, Nigeria

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Abstract

Cement factory dust (CFD) and Kiln feed dust (KFD) were examined using the indexes of pollution. Mean contamination indexes were calculated for each dusts relative to mean background concentrations of the elements in continental crust. Enrichment factor (EF) result showed significant enrichment of the CFD with Arsenic and Manganese, while Chromium, Iron as moderately enriched. Enrichment trend revealed As > Mn > Fe > Cr > Zn > Co > V. The result for the KFD indicated mercury, Arsenic, antimony, and Manganese to be significantly enriched and the order of the enrichment follows the pattern Hg > As > Sb > Mn > Zn > Fe > Co > Cr > V for the metals studied. The EF values for Zn, Co and V in CFD and Fe, Cr, Co, and V in KFD were within the deficient range which and the measure of EF for As, Mn, Hg and Sb suggest these metals could be of anthropogenic source. The measure of contamination based on pollution index (PI) for CFD indicated As and Mn to have moderate contamination while Cr, Co, Zn, V, and Fe to be at levels below contamination of significance. The trend of pollution according to the PI occurs in the order As > Mn > Fe > Cr > Zn > Co > V for CFD and Hg > Cr > As > Sb > Mn > Zn > Fe > Co > V for KFD. The PI model Categorized Hg, Cr, As and Sb in the KFD as within the medium contamination range. Geo-accumulation index (Igeo) showed CFD to be moderately polluted with As and Mn. Nevertheless, the trend of Igeo values in CFD increases in the order As >Mn> Fe > Cr > Zn > Co > V and Cr > As > Sb >Mn> Zn > Fe > Co >V > Hg for KFD. According to the Igeo, metal contamination in KFD was categorized into unpolluted to moderately polluted for Cr and As while Sb, Mn, Zn, Fe, Co, V, and Hg were classified into practically unpolluted range. The level of contamination of CFD and KFD with heavy metals was generalized by the modified degree of contamination (mCd) model as nil and Pollution load index model classified the dusts as having perfect condition but may require detailed study.

Keywords: Contamination indexes, Heavy Metals, Cement dust, Kiln feed dust, Pollution.

Introduction

The increasing construction works in Nigeria has spurs increased demand for Portland cement, which brought about the establishment of many cement industries in the country. The cement production processes has always been accompanied with the emission of dust to air. The introduction of dust traps in most cement factories, stray dust have been reduced tremendously. The entrapped dust settles in the factory confinement along production line and this may constitute a serious threat to occupational staff. The left-over dust can be cement or raw materials that are of geological origin. Dust exposure has been reported to occur among workers in cement factories[1-3].

Achternbosch and Bräutigam[4] reported the presence of Sb, As, Pb, Cd, Cr, Co, Cu, Mn, Ni, Thallium, Sn, V, Zn, Be, Se, Tellurium and Hg. With metal enrichment in the dust, their toxic nature and threat to human life can be a challenge for man's effort to enjoy a decent life as suspended dust particles have the greatest probability of interacting with human beings to the extent it can affect public health directly. As, Cd, Hg Pb, Cr and Ni are known neurotoxins, Carcinogens and some of which can cause skin lesion[5-14]. According to a review work by Wuana and Ekieimen[15], heavy metals occur naturally at <1000mg kg−1 in the soil environment due to pedogenetic processes of weathering[16,17].

Heavy metals essentially become contaminants in the soil environments because of their rates of generation via manmade cycles that are more rapid relative to natural ones[18]. In the assessment of environmental material for contamination by metals, chemical contaminants are evaluated and compared with the original pre-industrial concentrations[19,20]. This work was aimed at establishing occupational dust contamination of a cement factory.

Study Area: Ashaka Cement Company[21] supply the cement demand of North - eastern Nigeria. The communities around the company are mostly peasant farmers that are into subsidiary farming where maize, sorghum, millet, beans and ground nut are the major crops cultivated.

Materials and Methods

Sample Collection and Pre-treatment: Cement dust was scraped from surfaces at different sites inside the factory using paper and dried according to Wufem *et al.*[22] and Kpeglo *et al.*[23]. Dusts were oven dried, cooled and were analysed for metal concentration.

Elemental and Data Analysis: Elemental compositions of all samples were analysed using neutron Activation analysis technique[22]. The analysis of elemental concentration data was performed to evaluate the level of dust metal enrichment and contamination using various Indexes of contamination based on calculations adopted from soil models[24].

Enrichment Factor: Enrichment Factor is the ratio of the concentration of an element of interest (X_n) in the sample to that of a reference element (C_n) in the sample; i.e., $(X_n/C_n)_{sample}$, divided by the same ratio in a reference material, $(X_n/C_n)_{ref}$.

i.e $$\frac{(X_n/C_n)_{Sample}}{(X_n/C_n)_{Ref}} \quad (1)$$

The reference element is generally chosen from the elemental abundances in the Earth's crust[25]. In this study Scandium was chosen as the reference element because of its low volatility and rarely enters atmospheric aerosol from anthropogenic source[26]. Using the mean elemental abundances of Earth's crust given by Fortescue[27] the EFs were derived for Heavy metals in the cement factory dust and kiln feed dust of Ashaka cement factory.

The measure of contamination, according to the enrichment factor model, has been categorized into five.

EF < 2 - state of deficiency to minimal enrichment, EF = 2-5 - state of moderate enrichment, EF = 5-20 – state of significant enrichment, EF = 20-40 - very high enrichment and EF > 40 – extremely high enrichment[28,29].

Szefer *et al.*[30], had earlier suggested that EF values lower than and around 1.0 indicates theelement in the sediment to be predominantly from the crustal, or due to weathering process, and EF values greater than 1.0 shows the element to have anthropogenic origin. EF values less than 5.0 are not considered significant, because such small enrichments may arise from differences in the composition of local soil material and reference soil used in EF calculations[29]. The EF helps more importantly to differentiate between metals originating from anthropogenic activities and those from natural processes, as well as assessing the degree of anthropogenic influence[31]. But in view of natural variation of the Earth's crustal composition, EFs for elements show some degree of uncertainty, but the EFs should be an order of magnitude higher than unity[25] to suggest anthropogenic origin.

Pollution index (Contamination factor): Pollution index, often referred to as contamination factor have been used to assess environmental quality[32]. The Pollution Index defined sample contamination[33];

$$PI = C_{n\ sample}/C_{n\ background} \quad (2)$$

Where: $C_{n\ sample}$ and $C_{n\ background}$ are concentrations of elements in the dusts samples and average crustal concentrations respectively.

The calculation of contamination factor (CF) helps to provide a measure of the degree of overall contamination. The CF of each element was calculated and classified as either;

Low contamination for PI< 1, moderate contamination for $1 \leq PI < 3$, considerably contamination for $3 \leq PI < 6$, and very high contamination for $PI \geq 6$[34].

Geo-accumulation Factor: The index of geo-accumulation (Igeo) is widely used in the assessment of contamination by comparing the levels of heavy metals obtained and the original pre-industrial concentrations in the soils[35]. Addo *et al.*[33] also assessed road dust contamination[33] by Igeo. Igeo was computed by the following equation[35]:

$$Igeo = Log2\ [C_{n\ Sample}/1.5xB_{n\ background}] \quad (3)$$

Where: C_n represents the measured concentration of the element of interest *n,* B_n was the background content of element *n* in abundance of chemical elements in the continental crust. The constant 1.5 was introduced to minimize the effect of possible variations in the background values which may be attributed to lithologic variations in the sediments[35]. Geo-accumulation index was categorized according to Hu *et al.*[19] as; Igeo<0 = practically unpolluted, Igeo0-1 = unpolluted to moderately polluted, Igeo1-2 = moderately polluted, Igeo2-3 = moderately to strongly polluted, Igeo3-4 = strongly polluted, Igeo4-5 = strongly to extremely polluted and Igeo>5 = extremely polluted.

Modified Contamination Factor: A modified contamination factor (mCd) model according to Likuku *et al.*[35], was used to assess the general degree of contamination of the dust.

The equation for the calculation of the mCd is thus,

$$mCd = 1/N \sum_{N=i}^{N} CF_i \quad (4)$$

Where: mCd is the modified degree of contamination, CF the contamination factor as pollution index in equation[2], and N is the number of element analysed in the dust. This model interprets the contamination as; mCd< 1.5 – Nil to low degree of contamination, 1.5 ≤ mCd> 2 – low degree of contamination, 2 ≤ mCd> 4 – moderate degree of contamination, 4 ≤ mCd> 8 – high degree of contamination, 8 ≤ mCd> 16 – very high degree of contamination, 16 ≤ mCd> 32 – Extremely high degree of contamination, mCd ≥ 32 – ultrahigh degree of contamination.

Pollution Load Index: Pollution Load Index is a model for the estimation of levels of contamination and the needed action that would be employed in environmental materials. The Model as proposed by Tomlinson et al.[36] was used in this study to generally assess the condition of the dusts.

$$PLI = (CF_1 \times CF_2 \times (CF_3 \times (CF_4 \ldots\ldots\ldots\ldots x\ CF_N)^{1/N} \quad (5)$$

Where: all the terms are as given in equation[4]. PLI categorized the level of pollution in the environment as; PLI < 1 as Perfection, PLI = 1 as only baseline levels present, PLI > 1 as Deterioration of site quality, Likuku et al.[35] proposed an action that need to be taken as; When PLI ≥ 1, an immediate intervention is required, When 0.5 < PLI < 1, a more detailed study is required, When PLI < 0.5, it suggests no need for drastic rectification measure.

Results and Discussion

The contamination levels of heavy metals (Hg, As, Mn, Cr, Zn, Co, Fe, Sb and V) in Cement Factory dust (CFD) and Kiln Feed dust (KFD) were determined the using the models of measure of contamination indexes such as Enrichment factor (EF), Pollution Index (PI), Geo-accumulation index (Igeo), modified degree of contamination (mCd), and Pollution Load index (PLI). These methods have been employed by other researchers[33,35] to assess the level of contamination of metals in dusts. The results of the mean measure of EF, PI, Igeo, mCd and PLI for the CFD and KFD are given in Tables-1 and 2.

The Enrichment Factor for this study was calculated for each metal in the CFD and KFD relative to mean concentration of crustal values[25]. The result shows that the CFD contain highest concentrations of As followed by Mn. According to the EF, the contamination of the dust categorized As and Mn as significantly enriched, while Cr, Fe as moderately enriched. The model further classified Zn, Co, and V to be within the deficient to minimal enrichment range. The enrichment trend of the metals in the dust was As > Mn > Fe > Cr > Zn > Co > V. The EF result for the KFD indicates Hg, As, Sb and Mn to be significantly enriched while Zn was moderately enriched and Cr, Co, Fe and V were deficient to moderately enriched. The order of the enrichment follows the pattern of Hg > As > Sb > Mn > Zn > Fe > Co > Cr > V.

The EF result for the KFD indicates Hg, As, Sb and Mn to be significantly enriched while Zn was moderately enriched and Cr, Co, Fe and V were deficient to moderately enriched. The order of the enrichment follows the pattern of Hg > As > Sb > Mn > Zn > Fe > Co > Cr > V. The EF values for Zn, Co and V in CFD and Fe, Cr, Co, and V in KFD were within the deficient to minimal enrichment range which could be ascribed to natural process. According to Zhang and Liu[37], EF values in the range of 0.5 – 1.5 indicates that the metal is entirely from crustal material or natural processes, and EF greater than 1.5 shows that the metal might be of anthropogenic source. Based on this assertion, the results of the EF suggest Hg, As, Sb, Mn, and Sb to be of anthropogenic origin. Cement production is one of the key industrial sources of particulate matters (PM) and metals, especially copper (Cu), zinc (Zn), Pb, nickel (Ni), Cd, Hg and As, which are generated from both combustion of fossil fuels and processing of the raw materials[38,39]. Moreover, cement raw materials are mostly shales, limestone and sandstones that constitute sedimentary rock that contain 5% of trace element in the earth crust in which shales, limestone and sandstone make up 80%, 15% and 5% of the sedimentary rock respectively[40]. This serve as another source of heavy metals in the dusts in addition to incineration of tyres and coal, long vehicle exhaust etc.

Table-1
Calculated Measure of dust contamination derived from Relative abundance of Heavy Metals in the Earth Crust

Metal	Cement Factory Dust			Kiln Feed Dust			Relative Abundance in Earth's crust[27] (ppm)
	Enrichment Factors	Pollution Index	Geo-accumulation Index	Enrichment Factors	Pollution Index	Geo-accumulation Index	
Hg	-	-		20.76	3.02	-7.85	0.086
As	11.09	2.14	0.51	10.56	1.56	0.05	1.8
Cr	2.10	0.40	-1.89	1.22	1.83	0.29	122
Co	1.47	0.28	-2.40	1.24	0.18	-3.03	29
Zn	1.83	0.35	-2.09	2.23	0.33	-2.19	76
Mn	6.39	1.23	-0.29	6.59	0.97	-0.63	1060
V	1.16	0.22	-2.75	0.98	0.14	-3.38	136
Sb	-	-	-	8.82	1.30	-0.21	0.2
Fe	2.15	0.41	-1.86	1.59	0.23	-2.68	62,600

Pollution index is used as a contamination factor to assess environmental quality[32]. Figures-1 and 2 are the charts that compare the PI for various elements studied. From the PI for CFD and KFD shown in Figures-1 and 2 measure of contamination of As and Mn in CFD and Hg, As, Sb, Mn in KFD were above 1 and as such could be in levels of significant contamination. As and Mn could be classified to fall into a moderate contamination range while Cr, Co, Zn, V, and Fe to be at levels within low contamination range in CFD. According to PI model, contamination is classified as low contamination for PI < 1, moderate contamination for 1 ≤ PI ≥ 3, considerably contaminated for 3 ≤ PI < 6, and high contamination for PI ≥ 6. The degree of pollution of the dust by the metals occur in the order As > Mn > Fe > Cr > Zn > Co > V for the CFD. The trend in KFD was slightly different from that of CFD with Hg > Cr > As > Sb > Mn > Zn > Fe > Co >V. Hg, Cr, As and Sb in the KFD were classified in the category of medium contamination while Mn, Zn, Fe, Co, and V were in the low contamination range. The result of the mean geo-accumulation values for the metals in CFD and KFD (Table-1) shows that the measure of contamination of CFD with As and Mn were within the unpolluted to moderately polluted range while Fe, Cr, Zn, Co and V occur within the practically unpolluted range in the CDF. Nevertheless, the trend of Igeo values increases in the order As > Mn > Fe > Cr > Zn > Co > V. This trend differ in KFD as it indicates Igeo to increase in the order Cr > As > Sb > Mn > Zn > Fe > Co >V > Hg. According to the Igeo, the measure of contamination could be categorized into unpolluted to moderately polluted for Cr and As while Sb, Mn, Zn, Fe, Co, V and Hg could be classified as within the practically unpolluted range. The negative Igeo index values of the metals (Table-1) in the two dust types are result of deficient to minimal enrichment and/or relatively low levels of contamination[35].

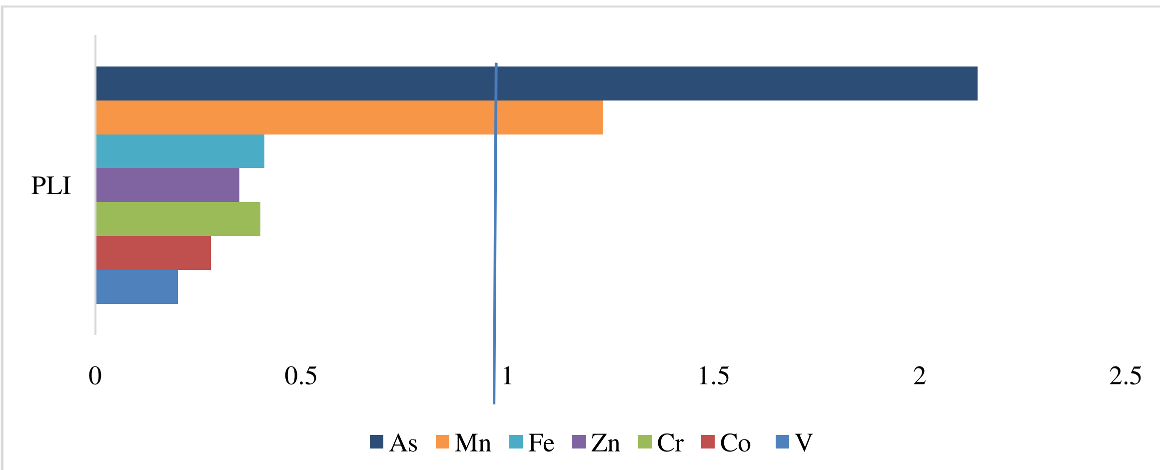

Figure-1
Pollution Indexes for the various elements in CFD

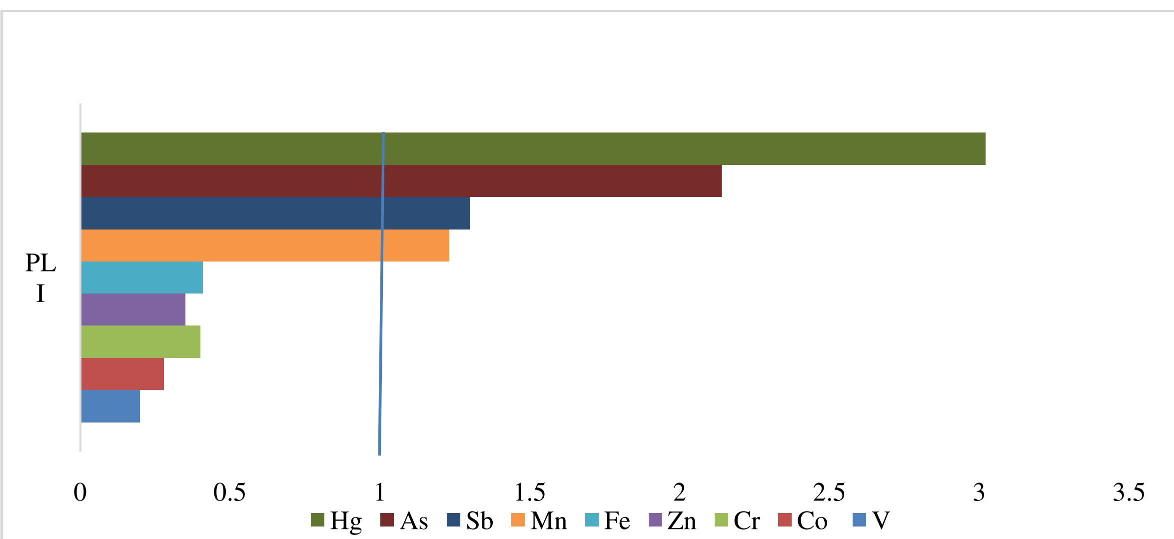

Figure-2
Pollution Indexes for the various elements in KCD

The interpretation of all the three contamination indexes used in this study seems to agree to some degree in explaining the trend in the contamination levels of the metals in the dusts and similar agreement was also observed in the three contamination indexes by Addo et al.[33]. This indicates that these models could serve as an effective tool in describing the trends of multi-element contamination of dust than they would have done in complimenting each other while categorizing the degree of pollution.

The general level of contamination of the dust with heavy metals was also assessed using the modified degree of contamination (mCd)[35] and the pollution load index. The results of mCd and PLI are given in Table-2. According to mCd, cement factory dust and Kiln feed dust generally have nil to very low degree of contamination while Pollution load index classified the two dusts as having perfect condition but may require detailed study. The mCd and mCd provide general pollution condition of the dusts based on all the metals analysed and indicated marginal contamination of the dusts that would require detailed study to determine the source of the metals and what action that would need to be taken.

Conclusion

The Enrichment Factor of this study was calculated for each metal in the CFD and KFD relative to the concentration of mean crustal values. The result shows that the CFD contain highest concentrations of As followed by Mn. According to the EF, the contamination of the dust categorized As and Mn as significantly enriched, while Cr, Fe as moderately enriched and Zn, Co, and V to be within the deficient to minimal enrichment range. The enrichment trend of the metals in the dust was As > Mn > Fe > Cr > Zn > Co > V. The result for the KFD indicated Hg, As Sb and Mn to be significantly enriched while Zn was moderately enriched and Cr, Co, Fe and V were deficient to moderately enriched. The order of the elemental enrichment follows the pattern of Hg > As > Sb > Mn > Zn > Fe > Co > Cr > V. The EF values for Zn, Co and V in CFD and Fe, Cr, Co, and V in KFD were within the deficient to minimal enrichment range which can be ascribed to natural processes. The measure of contamination based on PI classified the metal levels as As and Mn to have a moderate contamination while Cr, Co, Zn, V, and Fe to be within the low contamination range in CFD. The degree of pollution of the dust by the metals occur in the order As > Mn > Fe > Cr > Zn > Co > V for the CFD. The trend in KFD was Hg > Cr > As > Sb > Mn > Zn > Fe > Co > V. Hg, Cr, As and Sb in the KFD are classified as having medium contamination while Mn, Zn, Fe, Co, and V were in the low contamination range. According to Igeo index the measure of contamination of CFD with As and Mn were within the unpolluted to moderately polluted range while Fe, Cr, Zn, Co and V occur within the practically unpolluted range in the CDF. The trend of Igeo values increases in the order As > Mn > Fe > Cr > Zn > Co > V for CFD and differ from KFD as it Igeo to increases in the order Cr > As > Sb > Mn > Zn > Fe > Co > V > Hg. According to the Igeo the measure of contamination for KFD could be categorized intoo moderately polluted for Cr and As while Sb, Mn, Zn, Fe, Co, V, and Hg could be classified as within the practically unpolluted range. The negative Igeo index values of the metals (Tables-1) in the two dust types were a result of deficient to minimal enrichment and/or relatively low levels of contamination[35]. The interpretation of all the three contamination indexes seems to agree to some degree in explaining the trend in the contamination levels of the metals in the dusts suggesting that these models could serve as an effective tool in describing the trends of multi-element contamination of dust than they would have done in complimenting each other when categorizing the degree of pollution. The level of contamination of the dust with heavy metals was generalized by modified degree of contamination (mCd) and pollution load index in which mCd categorized the cement factory dust and Kiln feed dust as nil to very low degree of contamination and Pollution load index classified the two dusts as having perfect condition but may require detailed study. The mCd and mCd provided general pollution condition of the dusts based on all the metals analysed and indicated marginal contamination of the dusts that would require detailed study to determine the source of the metals and what action that would need to be taken.

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Table-2
Degree of contamination and Pollution load of Dust

Contamination parameter	Cement Factory Dust		Kiln Feed Dust	
	Values	Interpretation	Values	Interpretation
Modified Contamination Factor	1.49	Nil to very low degree of contamination[35]	1.37	Nil to very low degree of contamination[35]
Pollution Load Index	0.78	Shows perfect dust condition but may require detailed study[35]	0.72	Shows perfect dust condition but may require detailed study[35]

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