Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
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Journal of Applied Sciences 7 (1): 35-40, 2007
ISSN 1812-5654

Analysis of Potentially Toxic Metals in Airborne Cement Dust Around Sagamu, Southwestern Nigeria

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Abstract: This study analyzed the concentration levels of potentially toxic and harmful elements contained in the airborne cement dust generated in the vicinity and farther away 500 m in the conventional four cardinal directions from the West African Portland Cement Company (WAPCO) factory mill, Sagamu. The results indicated that the concentration range of these toxic elements fall between 40.0 and 280,000 μg g^{-1} in the cement dust samples. Also, the concentration range of these toxic elements in 1 L of air samples varies between 0.01 μg g^{-1} and 29.92 μg L^{-1}. The results generally show elevated concentrations of all the elements when compared with USA threshold limit of particulate metal concentration (e.g., Pb (1.5 g m^{-3}); Cd (0.004-0.026 g m^{-3}) in the air. These elements in the airborne cement dusts may pose a great threat to the health of plants, animals and residents in and around the factory and also to workers and visitors to the factory.

Key words: Potentially toxic metal, air particulate, cement dust, Sagamu, Nigeria

INTRODUCTION

Cement production is characterized by particulate air pollutant and essentially dust. Aina (1990) observed that 80% of atmospheric pollution comes from industrial emission in which cement and steel factories are more pervasive. It has also been observed that out of the 360 pounds/ton of cement produced, majority of them are from cement kiln. Besides, cement dusts are produced during blasting of raw materials, grinding of cement clinker and packaging or loading of finished cement (Bankole, 2003). Dusts according to Fenelly (1975) have wide range of sizes, usually less than 30 mm in diameter and varied in chemistry. Unlike dust from acidic rock quarries which are relatively inert, dust from the limestone according to Everest (1980) are highly alkaline with pH varying between 6.0 and 12.0 (Cawse *et al*., 1989; Arslan and BoyBay, 1990) and also contain metal constituents that have direct toxic effect (Darley, 1966). Some of the numerous components of cement dust include alumina, silica, polychlorinated dioxins and furans, mercury, antimony, cadmium, lead, zinc, chromium, arsenic and manganese (NPI, 1991). Majority of these constituents are Potentially Harmful Elements (PHEs) to the biotic components of the environment. Despite these adverse effects, cement is widely used in building and construction works as a key ingredient in concrete products. It is a binding agent that holds sand and other aggregates together in a hard stone like mass. Portland cement accounts for about 95% of the cement produced in North America. It is also, together with blended cement, the most commonly used cement in Nigeria. Production of Portland cement requires primary raw materials like limestone, chalk, cement rock and corals; secondary materials like shale, clays, sand and siltstones. Other required materials include iron ore, bauxite, fly ash and red alluvium. Production of cement is achieved by wet processing method. This study investigate the concentration levels of potentially harmful toxic metals in the air and cement dust generated in the vicinity and farther away (i.e., 500 m) in the four cardinal directions from the West African Portland Cement (WAPCO) mill, Sagamu area of southwestern Nigeria. From the results the pollution indices of these metals are determined and mitigation measures are suggested.

MATERIALS AND METHODS

The study area: Sagamu, the third largest settlement in Ogun state after Abeokuta and Ijebu Ode, is located within latitude 6°50′ and 7°00′ N and longitude 3°45′ and 4°00′ E. Sagamu works, the second works of WAPCO

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where this study was carried out is strategically located within the system of urban centers. It is 63 km southeast of Abeokuta, 72 km southeast of Ibadan, 67 km northwest of Lagos and 32 km west of Ijebu ode. The area stands on a low-lying gently undulating terrain with altitude ranging between 30 and 61 m above sea level. The area is characterized by high annual temperature, high rainfall, high evapotranspiration and high relative humidity which makes it to be classified as humid tropical region (Iloeje, 1981; Oguntoyinbo *et al*., 1983; Akanni in Onakomaya, 1992).

Geological setting: According to Kehinde-Phillips (1992), geology of Ogun state in which sagamu - the study area is a part, comprises of sedimentary rocks which underlie approximately three-quarters of the whole surface area of the state stretching from the northwest to the southeast and Basement complex rocks which underlie the remaining one-quarter of the surface of the state. The basement complex according to Jones and Hockey (1964) is made up of magmatite-gneiss complex, the schist belt and the older granites which are 800 to 500 million years in age (Hurley *et al*., 1967). These rocks are well displayed in Odeda, Abeokuta, Igbo-ora, Ijebu Igbo etc. The sedimentary rocks of Ogun state consist of Abeokuta formation (Rayment, 1965; Adegoke, 1969) later known as Abeokuta group-consisting of Ise Formation, Afowo formation and Araromi formation (Omatsola and Adegoke, 1981). The Abeokuta group which is Neocomian to Maastrichtian in age is overlain by Ewekoro formation which is Paleocene in age and Ilaro formation of Eocene age. Ewekoro formation is highly fossiliferous and consists of economic deposits of limestone that is presently quarried by WAPCO in Ewekoro and Sagamu, respectively.

Field sampling techniques: A total of thirty six (36) dust and air samples collected at interval of 100m from the mill (i.e., 0.0 m) using air sampler disc mounted with 4.5 micron filter paper were analyzed in this study. The air sampler was used to sample the dust in the air at different points (i.e., 100, 200, 300 and 500 m) from the mill, which serve as the reference point (i.e., 0.0 m) along each of the cardinal points (i.e., east, west, south and north). The dust from the air was sucked into a 4.5 microns filter paper placed in a disc having an air inlet attached to a battery controlled air pump. The sampling of the air was carried out on a height of 1.5 m above the ground for a period of 2 hrs at each point. The airflow rate at each point of sampling was recorded. Each filter paper on which the air dust particles were collected was stored into a sampling disc at the site and taken to laboratory for analysis. Dust samples collected at intervals of 100, 200, 300 and 500 m in each of the four cardinal points from the mills over a period of four months was also analyzed to compliment the air sample results.

Laboratory analysis: Each filter paper containing the dust particulates were measured and from the weight obtained the initial weights of the filter papers were deducted in order to obtain the weight of dust collected from each point. Each filter paper was digested along with the dust on it using concentrated nitric acid and distilled water at a ratio 1:2 (i.e., 15 mL of acid to 10 mL of water) in a conical flask and placed on a heating mantle. The resultant solutions were made up to the 50 mL mark in a volumetric flask. A blank digestion was also carried out as a check. The digested samples were analyzed for the arsenic (As), cadmium (Cd), cobalt (Co), lead (Pb), aluminium (Al), iron (Fe), zinc (Zn) and chromium (Cr) using Atomic Absorption Spectrometer (AAS).

Data interpretation: The data obtained from the chemical analysis were subjected to statistical treatment using correlation coefficient matrices. This was carried out in order to establish element association and probable source of dispersion or pollution. From the data was deduced concentration ranges of the elements; their mean concentrations and standard deviations were also calculated. Besides, the clustered bar charts were produced to show the elemental concentration in both the air and the dust and also Pollution Index (PI) was calculated for each toxic pollutant in order to determine their load in air and dust media and their potential hazards.

RESULTS AND DISCUSSION

The data (Table 1 and 2) show a considerable abundance of the toxic metals at the cement works and its surrounding environments. However, it was discovered that the concentrations of all the metals are higher at the 500 m locations than at the 100 m locations especially in the southern and western directions of the mills. This probably implies that resident time and mobility of the metals in the air would have resulted into the metals settling down at distances further away from the main source. Thus, the farther the distance the higher the deposition. Besides, the higher concentration of elements recorded in both the western and southern directions of the reference point (i.e., the mill) can also be attributed to the presence of the quarry at the southern end and production activities in the western part of the

Table 1: Elemental concentrations of metals from dust samples

Location	As	Al	Ca	Cd	Pb	Co	Zn	Fe	Cr
	($\mu g\ g^{-1}$)								
W1 500	19000.0	32000.0	9000.0	8000.0	12500.0	500.0	11000.0	9500.0	750.0
W2 100	170.0	120.0	55.0	90.0	315.0	80.0	115.0	30.0	5.0
S1 500	280000.0	23500.0	13000.0	14000.0	24500.0	9000.0	205.0	2000.0	1000.0
S2 100	135.0	42.5	40.0	35.0	87.5	20.0	120.0	20.0	25.0
N1 500	642.9	1333.0	833.3	214.3	1142.9	285.7	714.3	238.1	47.6
N2 100	385.6	799.9	499.9	128.6	685.7	171.4	428.6	142.9	28.6
E1 500	363.6	204.6	250.0	386.4	556.8	170.5	340.9	90.9	18.5
E2 100	218.2	122.8	150.0	231.8	334.1	102.3	204.5	54.5	10.9

W-West, S-South , E-East and N-North

Table 2: Elemental concentrations of metals from air samples

Location	As	Al	Ca	Cd	Pb	Co	Zn	Fe	Cr
	($\mu g\ L^{-1}$)								
W1 500	1.650	2.780	0.780	0.690	1.090		0.960	0.830	
W2 100	0.018	0.013	0.005	0.010	0.034	0.009	0.012	0.003	0.001
S1 500	29.920	2.510	1.390	1.500	2.620	0.960	0.027	0.210	0.110
S2 100	0.010	0.003	0.003	0.003	0.007	0.002	0.009	0.002	0.002
N1 500	0.056	0.116	0.072	0.019	0.099	0.025	0.062	0.021	0.004
N2 100	0.034	0.070	0.043	0.011	0.059	0.015	0.037	0.013	0.002
E1 500	0.036	0.020	0.025	0.038	0.055	0.017	0.034	0.009	0.010
E2 100	0.022	0.012	0.015	0.025	0.033	0.010	0.021	0.005	0.010

W-West, S-South, E-East and N-North

Table 3: Statistical parameters for elemental concentrations of metals in dust samples

Elements	Concentration range ($\mu g\ L^{-1}$) Minimum	Maximum	Mean concentration ($\mu g\ L^{-1}$)	Standard deviation
As	135.0	280000	37614.41	98156.61
Al	42.5	32000	7265.39	12853.31
Ca	40.0	13000	2978.53	5071.79
Cd	35.0	14000	2885.76	5259.74
Pb	87.5	245000	5015.25	8924.95
Co	20.0	9000	1404.27	3350.46
Zn	115.0	11000	1641.04	3786.77
Fe	20.0	9500	1509.55	3297.40
Cr	5.0	1000	221.24	435.60

Table 4: Statistical parameters for elemental concentrations of metals in 1 L of air samples

Elements	Concentration range ($\mu g\ L^{-1}$) Minimum	Maximum	Mean concentration ($\mu g\ L^{-1}$)	Standard deviation
As	0.010	29.92	3.97	10.50
Al	0.003	2.78	0.69	1.21
Ca	0.003	1.39	129.99	367.29
Cd	0.003	1.50	0.28	0.54
Pb	0.007	2.62	0.49	0.93
Co	0.002	0.96	0.15	0.36
Zn	0.009	0.96	0.14	0.33
Fe	0.002	0.83	0.13	0.29
Cr	0.001	0.11	2.38	4.42

mill which invariably have increased the quantity of the dusts and also elemental concentrations at these locations/directions. Simple descriptive statistical analysis of elemental concentrations of metals in the dust samples indicates the highest mean concentrations for arsenic (27614.41 $\mu g\ L^{-1}$) followed by aluminium (7, 265.40 $\mu g\ L^{-1}$) and also least for chromium (221.24 $\mu g\ L^{-1}$) (Table 3). The same analysis for 1 L of air samples recorded the highest mean concentration for arsenic (3.97 $\mu g\ L^{-1}$) followed by chromium (2.38 $\mu g\ L^{-1}$) and least for iron (0.13 $\mu g\ L^{-1}$) (Table 4).

Further statistical analysis indicated a very strong correlation between the elements analyzed in the samples from the study area. Table 5 shows a positive relationship between almost all the metals except zinc, which shows a negative relationship with arsenic, cobalt and chromium. The relationship between the metals in the dust samples is most significant at the level of 0.01 (i.e., $p>0.01$) while correlation between zinc and aluminium is only significant at the level of 0.02 (i.e., $p>0.02$). The same pattern of relationship between the metals in the dust samples was also observed in the air samples (Table 6) except that in addition, zinc shows a negative relationship with calcium in the air sample medium. Also, the correlation between the metals in the air samples is only and very strongly significant at the level of 0.01 (i.e., $p>0.01$). Both cobalt and chromium show very strong significant relationship at a level of 0.01 (i.e., $p>0.01$) with all the metals except zinc. Also, very strong and significant correlation exists between nearly all the elements analyzed and calcium which is one of the main components of cement. However, the situation is not the same with iron which shows a weak correlation (i.e., $p>0.082$) and a very weak correlation (i.e., $p>0.81$) with calcium and also zinc which shows a very weak correlation (i.e., $p>0.24$) and ($p>0.73$) with calcium in both the dust samples and air samples, respectively.

Table 5: Correlation coefficient matrix of analyzed elements In the dust samples

	As	Al	Ca	Cd	Pb	Co	Zn	Fe	Cr
A	1.000								
Al	0.567	1.000							
Ca	0.837**	0.925**	1.000						
Cd	0.887**	0.883**	0.994**	1.000					
Pb	0.912**	0.855**	0.988**	0.988**	1.000				
Co	1.000**	0.999**	0.999**	1.000**	1.000**	1.000			
Zn	0.087	0.771*	0.472	0.383	0.330	-0.180	1.000		
Fe	0.126	0.889**	0.648	0.571	0.522	0.997**	0.977**	1.000	
Cr	0.999**	1.000**	0.999**	1.000**	1.000**	1.000**	-0.214	0.997**	1.0

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level

Table 6: Correlation Coefficient Matrix of Analyzed Elements In the Dust Samples

	As	Al	Ca	Cd	Pb	Co	Zn	Fe	Cr
As	1.000								
Al	0.650	1.000							
Ca	0.999**	0.609	1.000						
Cd	0.923**	0.891**	0.902**	1.000					
Pb	0.940**	0.871**	0.920**	0.999**	1.000				
Co	1.000*	1.000**	1.000**	1.000**	1.000**	1.000			
Zn	- 0.091	0.697	- 0.144	0.297	0.255	- 0.026	1.000		
Fe	0.156	0.852**	0.103	0.523	0.484	0.998**	0.969*	1.000	
Cr	1.000**	1.000**	1.000**	1.000**	1.000**	1.000**	0.043	0.998**	1.00

** Correlation is significant at the 0.01 level

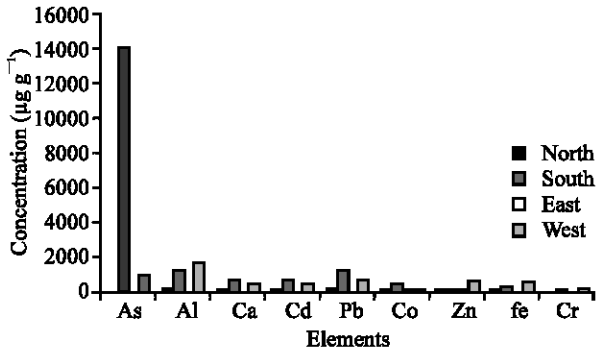

Fig. 1: Clustered chart of mean element concentration of dust smaple

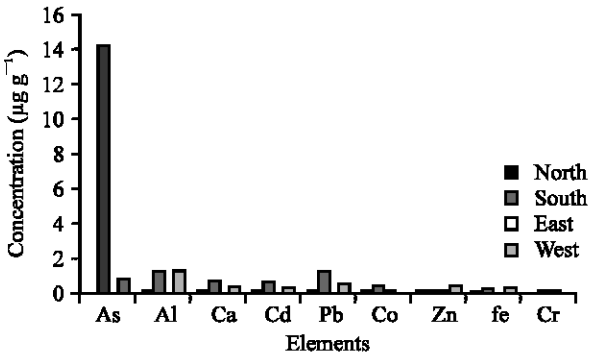

Fig. 2: Clustered chart of mean element concentration of air smaple

This implies that all other elements are from the same source (i.e., cement dust). Since iron and zinc gives a very strong correlation (i.e., p>0.00) with one another in both the dust and air samples, it then suggests that they are from the same source. The strong correlation between iron and aluminium (p>0.003 and p>0.007), zinc and aluminium (p>0.02 and p>0.05) in dust and air samples could be as a result of contamination from the precipitator stack due to rust. Generally, the values obtained from the study site far exceed the stipulated standard of PM 2.5 (particulate matter less than 2.5 µm in diameter) for personal exposure (CARB, 2002) and also exceed personal exposure levels for PM in Alberta (Norman, 2002). The clustered bar charts (Fig. 1 and 2) confirm the trending pattern of high concentration of the elements in both the dust and air samples along the southern and western directions of the cement mill. Also, the pollution index employed in this study defines the extent or degree of pollution of the toxic elements in air and dust collected from the study area. It is calculated using the ratio of average elemental concentration in air or dust to the standard of element in air. The pollution indices less than 2 (i.e., PI<2) in this study are considered not significant while those above 2 (i.e., PI>2) are significant. The charts of pollution indices (Fig. 3) for the study area indicate lead (Pb) as the greatest pollutant in all the four directions followed by arsenic (As) in the air and dust along the southern and western directions. Similarly, cobalt (Co) is relatively pronounced in the air and dust collected in the northern and eastern directions.

The health effect of toxic metals in air and dust from cement factory on human is better appreciated if one consider the fact that an active person typically inhales 10, 000 to 20, 000 L of air daily (i.e., 7 to 14 L per min). This intake increases with vigorous exercise (Derek, 1996).

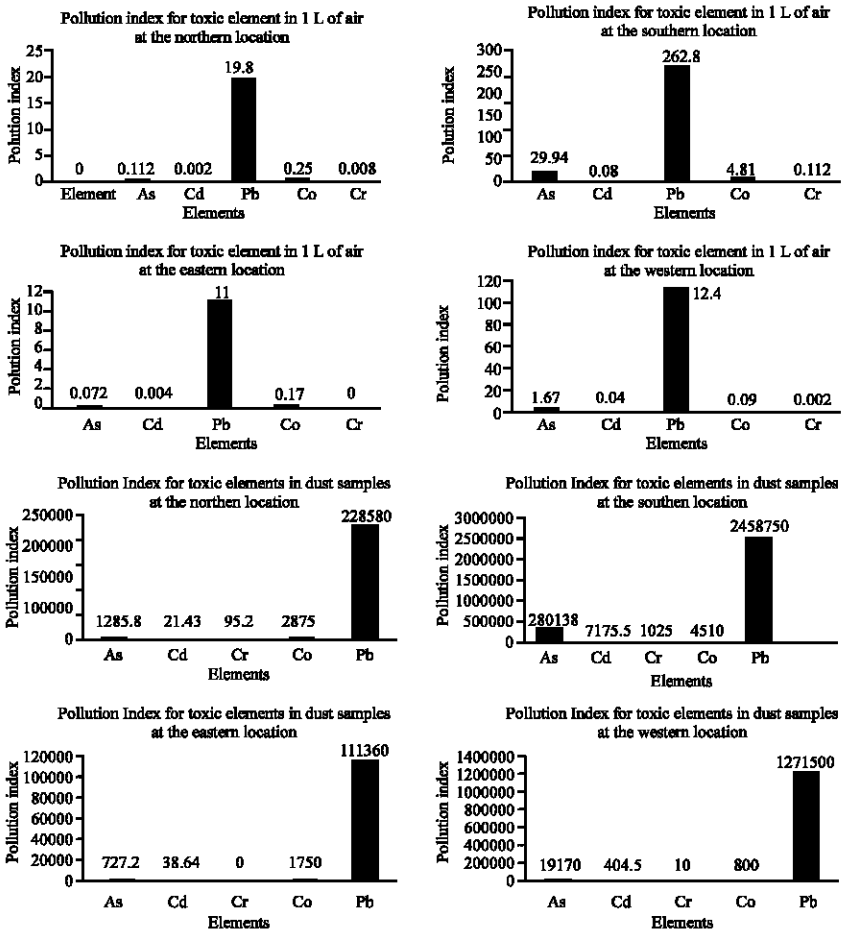

Fig. 3: Pollution indices for toxic element in air and dust samples from the study area

As air is taken into body so also are the particulate and gaseous pollutants. During the inhalation and exhalation, these pollutants can inflame, sensitize and even scar the lungs and tissues. The pollutants may enter the numerous tiny air sacs deep inside the lungs and also the blood stream thereby affecting several other organs than lung. These elevated concentrations of arsenic, cadmium, chromium, cobalt and lead in both southern and western part of the mill may account for more health problems among the inhabitants of the communities in these two wind directions than those in the northern and eastern portion of the mill where the concentration of these metals are low in the airborne dust. Many of the possible serious health problems of these airborne dust pollutants on human include asthma, irritation of the lungs, bronchitis, cancer, pneumonia, decreased resistance to respiratory and early death (EPA, 2001).

Apart from the direct health problem on man, adverse effect of airborne dust pollutant on the ecosystem in general are ozone layer depletion, green house effects and acid rain (Mellanby, 1988). Specifically, dust from cement factory adversely affect the forest ecosystem, soil enzyme, fungi and bacteria population within the vicinity of the factory (Khosla and Parmer, 1988). It increases the soil pH and sulphur and also affect phosphorous quantity and behaviour thereby affecting seed germination. Dust from cement factories according to Amira (2002) is capable of changing salt content of water hence seriously disrupting aquatic communities and also decrease quality of water used for drinking and irrigation purpose. Cement dust is capable of increasing water turbidity and reducing light penetration. It can also result in deficiency of certain minerals and environmental factors like extreme water hardness or elevation of carbon dioxide which will give rise to other pathological conditions (Landolt, 1975). Sree Rangaswani *et al.* (1973) observed that deposition of cement dust on herbaceous plants and fruit crops can cause effects that range from blocked stomata, reduced number of plant leaf and injury to complete reduction in vegetative growth and reproductive structures.

CONCLUSIONS AND RECOMMENDATION

This study has shown that there is significant emissions of airborne pollutant into the environment around WAPCO works Sagamu, up to 500 m distances from the mill in the four cardinal directions. This emission is capable of posing a serious health risk to workers and residents even at a distance of 500 m away from the mill. Besides, the presence in high concentrations of these toxic metals in the generated cement dusts are indicators of possible lethal effect on both the terrestrial and aquatic habitat with resultant negative impact on all the living organisms. The emitted cement dust can also affect soil property and quality of water resources in the study area. However, the use of electric precipitator for dust removal and recycling is recommended. Compliance with the new standard of 20 mg m^{-3} and proper monitoring of air emission of cement dust in the area will help in reducing the impact of airborne pollutant on the environment. Use of safety wears in workplace and premises of the factory to ensure the good health of the workers and factory visitors is advocated.

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