Original Research

Pollution Loads and the Ecological Risk Assessment of Soil Heavy Metals around a Mega Cement Factory in Southwest Nigeria

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Abstract

Cement production is noted for particulate pollution of the environment because of high dust emissions and heavy metals that later deposited in soils, serving as a sink. This study aimed to assess the concentrations and potential ecological risk of heavy metals around a mega cement factory in southwest Nigeria. Soil samples were randomly collected in the eastern, western, and southern axes of the factory. The samples were subjected to Nitric-perchloric acid digestion, and an atomic absorption spectrophotometer was used to determine the concentrations of Pb, Cu, Cd, Cr, and Zn. Data were analyzed with ANOVA and Duncan Multiple Range Test. The results showed that the mean concentrations of Pb, Cu, Cd, and Cr (666.1 mg/kg, 613.4 mg/kg, 547.9 mg/kg, and 188.5 mg/kg, respectively) were above the international standard limits. Nemerow pollution indices, according to the axes, indicated serious pollution with heavy metals. The Single Potential Ecological Risk Index (PERI) showed that soil contamination from Cd in the 3 axes had very high potential ecological risk, which translated into the high value of Comprehensive Potential Ecological Risk (RI) value (11,488.3) for the entire study area. The urgent need for the bioremediation of the soil around the cement factory, especially for Cd, is needed to avert a potential environmental disaster.

Keywords: potential ecological risk index, contamination, pollution load, bioremediation, cement factory

Introduction

Heavy metal contamination of the environment is a worldwide problem that has attracted a great deal of attention [1]. One of the major routes of heavy metals introduction into the environment is rapid industrialization [1], including dust emissions from cement production and its heavy metal contamination of the environment [2, 3]. Soils are regarded as the ultimate sink for heavy metals discharged into the environment [4, 5]. Heavy metals can be sensitive indicators for monitoring environmental contamination [6].

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It is also reported that contents of various chemical elements in soil affect the intensity of biological processes as well as deciding whether dietary intake of a given product is safe for consumption [7]. Liang et al. [8] also stated that heavy metals are potentially toxic to crops, animals, and human when contaminated soils are used for crop production, because heavy metals are easily accumulated in vital organs of crops grown on these contaminated soils. Humans and animals that consume such crops are also prone to this potential toxicity [8]. This has really given impetus to the study on environmental problems of soil pollution by heavy metals in the last few decades [9] with the development of an ecological geochemistry survey to aid in determining levels of heavy metal pollution and its potential risk.

Qingjie et al. [1] stated that a great deal of data related to soil or soil pollution load by heavy metals can be measured to assess the quality of ecological chemistry environment. Ecological risk assessment of heavy metals in polluted soils has been gaining more attention in recent years [6, 10, 11]. The ecological risk assessment can reveal the possibility of soil being polluted, and even for the ecological function to be harmed by concerned heavy metals [12]. In contrast, Wu et al. [13] has stated that more studies and practices have shown that such results from risk assessment have little capability to reveal the real degree of the potential toxic effects of metals without primary empirical research.

Though there is some published literature on heavy metal pollution of the air and dusts surrounding the West African Portland Cement Company (WAPCO), in southwest Nigeria [14], the impact and concentrations of heavy metals in soil have not been assessed. Therefore, the objective of this study was to assess the heavy metal concentrations and the potential ecological risk of the metals in the soils around a mega cement factory.

Materials and Methods

Study Area

The study area was around the West African Portland Cement Company factory, now referred to as Lafarge-Cement WAPCO, which started operations in 1978. The study area lies between latitude 6º50' and 7º00' N and longitude 3º45' and 4º00' E in southwestern Nigeria [14]. The area stands on low-lying, gently undulating terrain with altitude ranging between 30 and 61m above mean sea level [14]. The soil type of Sagamu is ferralitic and the climate is humid tropical climatic zone [15] and controlled by the tropical maritime and tropical continental air masses [16]. The mean annual rainfall, temperature, and monthly relative humidity were 1,400 mm, 26º and 70%, respectively [15].

Soil Sampling and Chemical Analysis

Topsoils (0-15cm) were sampled on the eastern, western, and southern axes within a radius of 5 km of WAPCO between August and October 2011 using the random sampling method [17]. The northern axis of WAPCO was swampy at the time of this study; therefore, samples were not collected from the axis. The co-ordinates of the sampling locations were recorded with a hand-held GPS (Garmin 72H) according to the method. Twenty-one representative samples of topsoil were collected in total; each sample representing a composite sample of at least 3 subsamples. The soil samples were air-dried in the laboratory to constant weight, after which the samples were crushed and passed through a 2 mm sieve to get fine fractions for chemical analyses. One gram of each sample was digested according to the conventional Nitric-perchloric acid digestion [18, 19]. The solution was filtered through a sintered glass and analyzed for total Pd, Cu, Cr, Cd, and Zn using atomic absorption spectrophotometry at wavelengths (λ) of Pb =283.3 nm, Cu = 324.8 nm, Cr = 357.9 nm, Cd =288.8 nm, and Zn = 213.8 nm. Quality assurance and control were assessed using the duplicates and blanks method [20].

Pollution Evaluation Method

The composite index method (Nemerow Index) according to Liang et al. [8] was adopted to evaluate the quality of the soil of the study area. The composite index method used the single pollution index (eq. 1), which more directly reflects the pollution of environmental indicators.

$$\text{Single Pollution Index } (Pi) = Ci/Cref \quad (1)$$

...where *Pi* is the single pollution index; *Ci* represents the mean concentrations of heavy metals from at least 5 sampling sites, and *Cref* indicates the evaluation criteria values [21]. The adopted evaluation criteria for this study was the recommended values for agricultural soil by the Canadian Council of Ministers for the Environment [22], as Nigeria has no stipulated guideline for heavy metals in soil.

The Nemerow Composite Index method (eq. 2) takes into account all the individual evaluation factors from equation (1), and also highlights the importance of the most contaminated elements.

$$\text{Nemerow Index } (P_s) = \sqrt{(P_{ave}^2 + P_{max}^2)\ /\ 2} \quad (2)$$

...where P_{ave} is the average of single Pollution Index of all metals and P_{max} is the maximum value of the single pollution index of all metals. The quality of soil environment is classified into 5 grades from the Nemerow pollution index: (P_s<0.7, safety domain; 0.7≤P_s<1.0, precaution domain; 1.0≤P_s<2.0, slightly polluted domain; 2.0≤P_s<3.0, moderately polluted domain; and P_s<3.0, seriously polluted domain [23]).

The potential ecological risk index method proposed by Hakanson [21] (eq. 3) to evaluate heavy metal contamination from the perspective of sedimentology was applied to evaluate the heavy metal pollution in the soils and also to associate ecological and environmental effects with their toxicology [11]. Although the risk factor is originally used as a diagnostic tool for the purpose of controlling water pollution, it has been successfully used for assessing the quality of sediments and soils in terms of heavy metals pollution [1].

$$\text{RI} = \sum_{i=`1}^{n} E_r^i ; E_r^i = T_r^i \times Pi \quad (3)$$

...where E_r^i is potential ecological risk individual coefficient, and T_r^i is the toxicity response coefficient of metal toxicity developed by Hakanson [21]. The toxicity response coefficients of Pb, Cu, Cr, Cd, and Zn were 5, 5, 2, 30, and 1, respectively, while the indices of potential ecological risks [21] are listed in Table 1.

Table 1. Risk grades of single and comprehensive potential ecological risks of heavy metal pollution.

E_r	Single-potential ecological risk (E_r)	RI	Comprehensive-potential ecological risk (RI)
<40	Low potential ecological risk	<90	Low potential ecological risk
$40 \leq E_r < 80$	Moderate potential risk	90≤RI<180	Moderate potential ecological risk
$80 \leq E_r < 160$	Considerable potential risk	180≤RI<360	Strong potential ecological risk
$160 \leq E_r < 320$	High potential risk	360≤RI<720	Very strong potential
≥320	Significantly very high	≥720	Highly – strong potential

Data Analysis

The data were analyzed with one-way Analysis of Variance (ANOVA) to test the differences of the variables under consideration. Duncan's Multiple Range Test was employed to separate means that were significantly different at P<0.05.

Results

Heavy Metal Distribution in the Soils

Concentrations of heavy metals in the topsoil of the study area are presented in Table 2. The mean concentrations of Pb, Cu, Cd, and Zn were 666.1 mg/kg, 613.4 mg/kg, 156.6 mg/kg, 547.9 mg/kg and 188.5 mg/kg, respectively. High metal concentrations in the soil were found for Pb, Cu, and Cd, while Cr had the least concentrations. The mean values of the heavy metal contents can be ranked in the order of Pb, Cu, Cd > Zn, and Cr (P<0.05) (Table 2). Considering international standard limits, Pb, Cu, Cr, and Cd were found to have concentrations in the soil that are higher than the Canadian Council of Ministers of the Environment (CCME) limits.

The pH value range of 5.60 to 5.89 for the studied axes suggests slight acidic conditions of the soils. The percentage of organic matter contents of the axes were 6.34 (east), 4.47 (west), and 4.13 (south), indicating soils with high organic matter and fertility (Table 3). Mean values of heavy metal contents of the axes are presented in Table 3. The value of Pb concentration (719.9 mg/kg) was numerically higher in the southern axis of the factory, but statistically the same with the western and eastern axes (655.4 mg/kg and 522.5 mg/kg respectively) (P<0.05). Mean concentrations of Cu (855.8 mg/kg) and Cd (707.4 mg/kg) were significantly higher in the soil of the western axis than the two other axes (P<0.05).

Assessment of Soil Pollution and Potential Ecological Risk

The calculated value of the Nemerow Composite Pollution Index (P_s) calculated for the three axes are presented in Table 4. The western axis had a higher Ps value (380.7) than the eastern (222.1) and southern (221.4) ones. The potential ecological risks of the heavy metals in the soils around the cement factory are also shown in Table 5. The highest single potential ecological risk (E_r) associated with each metal was found to be Cd, with values of 9176.4, 1581.0, and 9186.9 for the eastern, western, and southern axes, respectively. The values of E_r for Pb and Cu were within low to moderate potential ecological risk, whereas Cr and Zn were within low or no potential ecological risk (Table 5). The comprehensive potential ecological risk (RI) of the 3 axes ranged from 9,176.4 (eastern axis) to 15,810.6 (western axis) which means that each axis has a strong potential for ecological risk as indicated in the Hakanson Index. The contributing critical factor to the strong potential for ecological risk in each of the three axes (Table 5) was Cd, and this was consistent with the results of Nemerow Pollution Index Assessment.

Discussion

The distribution of metal in the soil around Lafarge Cement WAPCO indicates that there are several locations with high contents of Pb, Cu, Cd, and Cr, which were severely contaminated. The high contents of Pb, Cu, and Zn were consistent with the results of Bi et al. [25] and Wu et al. [13]. The contributing factor to this high soil contamination can be related to the combustion of leaded fuel by vehicles involved in different activities around the factory [4] coupled with the cement production activities that release dust containing Pb, Cu, and Cd [26]. Adekola et al. [27] in northwestern Nigeria indicated lower concentrations of Pb (8.54 mg/kg), Cu (15.08 mg/kg), and Zn (8.54 mg/kg) around a mega cement factory. This was attributed to the fact that the facilities and equipment were new and the operation period had not exceeded 10 years. In Jordan, Al-Kashman and Shawabkeh [28] also reported that soil around a cement factory had Pb concentration of 55 mg/kg, which is still lower than the finding of this study.

Compared to the mean concentrations of reported metal contents of urban soils [4, 29], the mean values of Pb, Cu, Cr, Cd, and Zn in this study were much higher than those reported. It is important to note that the Cd content of the soils is alarming, even for industrial soils where threshold in such soils should not be more than 22 mg/kg according to CCME guidelines [22]. The large amount of Cd that was supposed to be low in soils can be mainly ascribed to the

Table 2. Total heavy metal contents (mg/kg) of the topsoils.

Samples	Co-ordinates	Pb	Cu	Cr	Cd	Zn
1	6°48'57"N 3°36'11"E	712.1	862.2	99.8	764.1	106.2
2	6°48'50"N 3°36'80"E	688.2	898.8	86.4	692.1	136.4
3	6°47'01"N 3°34'80"E	712.1	761.1	140.6	811.1	400.2
4	6°48'77"N 3°36'44"E	709.8	869.2	92.2	601.2	509.2
5	6°49'84"N 3°37'91"E	742.1	672.2	64.1	422.8	99.8
6	6°48'24"N 3°35'81"E	800.2	841.2	18.8	962.1	153.1
7	6°47'31"N 3°37'06"E	99.8	366.4	69.2	638.1	121.1
8	6°47'77"N 3°34'00"E	299.4	968.8	102.6	692.1	243.2
9	6°48'34"N 3°36'62"E	686.2	632.1	103.8	504.8	100.6
10	6°47'97"N 3°38'03"E	985.2	346.2	99.1	609.2	101.1
11	6°48'11"N 3°36'90"E	298.8	999.2	142.1	700.8	121.1
12	6°47'29"N 3°38'74"E	867.7	200.4	322.1	342.1	200.8
13	6°47'11"N 3°38'90"E	699.2	96.2	362.1	806.4	92.1
14	6°47'65"N 3°38'85"E	804.1	343.8	99.8	79.9	91.1
15	6°47'69"N 3°38'06"E	863.2	897.2	126.1	96.8	72.1
16	6°48'05"N 3°36'38"E	992.1	869.4	288.2	642.1	56.1
17	6°48'42"N 3°38'07"E	968.4	666.6	204.6	538.1	109.6
18	6°47'30"N 3°38'85"E	906.1	392.2	199.8	466.2	388.1
19	6°48'35"N 3°38'08"E	489.9	296.1	201.2	492.1	446.2
20	6°47'69"N 3°38'86"E	398.2	99.9	199.6	604.8	308.8
21	6°48'26"N 3°38'96"E	266.1	802.4	266.8	39.9	100.9
	Mean	666.1^{a}	613.4^{a}	156.6^{b}	547.9^{a}	188.5^{b}
	S.D	258.9	300.2	91.7	244.6	137.5
	Ref (CCME, 2007)	70	63	64	1.4	200

Mean values with the different letters are statistically different at 5% probability level.

production activities of WAPCO. Awofolu [30] asserted that a high quantity of Cd release to the environment around a cement factory can only come from industrial activities and burning of fossil fuels. Al-Qud et al. [31] also reported significant enrichment of Pb, Cu, and Cd in the soils around a cement factory in Riyadh City, Saudi Arabia, which indicates that these metals are released along production the line of cement. Metal concentrations were compared to the CCME [22] standards for agricultural soils; the mean values of all the measured heavy metals studied, except Zn, were higher than the allowable limit in agricultural soils, especially for Cd, whose content was 547.9 mg/kg as against the recommended threshold of 1.4 mg/kg. These high metal concentrations in agricultural soils pose increased hazards of dangerous migration into underground water and eventual transfer up the food chain through plant uptake [32].

High metal contents of the soils across the axes of the cement factory gave a trend that can be attributed to the industrial activities around the facility. The quarry is located at the southeastern axis while the production activities are being carried out in the western region. This apparently gave reasons for the high metal contents recorded at the axes. Gbadebo and Bankole [14] reported high contents of Pb, Cu, Cr, Zn, and Cd in the air and dust samples of the western and southern axes, which conformed to this finding. The great amount of Cu content in the western axis can be attributed to the release of Cu from the production activities coupled with vehicular activities/oil combustion [33-35], since the region is close to a trunk A-road (dual-carriage expressway linking 2 state-capitals) and several trunk C-roads. Al-Khashman and Shawabkeh [28] also related the abundance of cu in soil of their study area to cement plant emissions. It is important to note that Cd content of the soils around the cement facility was too high, compared to international standard limits in agricultural and industrial soils. This finding on Cd was inconsistent with the reports of Al-Khashman and Shawabkeh [28] and Mandal and Voutchkov [36] on soils around cement facilities in Jordan and Jamaica, respectively.

Considering the potential ecological risk assessment of the study area, the soils of the 3 axes had strong potential ecological risk and Cd was found to be the main factor causing the serious risk of the soils. The input of Cd into the soils of the study area is of great concern because of its high toxic-response factor. It also is important to know that the soil of the western axis had the highest RI, which was the translation of the high Nemerow Composite Index recorded for the axis due to the various operations/activities at the axis. This report is consistent with the findings of several authors. Liang et al. [8], Wu et al. [13], and Qiu [24] reported that significantly high potential ecological risks were recorded in their studies, which mainly were products of high Cd load in the soils. Wei et al. [37] reported significantly high potential ecological risk of heavy metals of road dusts in NW China caused by heavy loads of Cd in the dust, while Yisa et al. [38] stated that Cd contributed 60.2% of the total potential ecological risk of heavy metals in the dust of Suleja, Nigeria.

Table 3. Mean values of chemical elements and heavy metal contents (mg/kg) in soil according to axis of the studied cement factory.

Chemical constituents	Eastern Axis	Western Axis	Southern Axis	(F)
$pH_{(-\log[H^+])}$	$5.66^{a}\pm0.40$	$5.89^{a}\pm0.36$	$5.60^{a}\pm0.30$	1.371
Organic matter (%)	$6.34^{a}\pm2.46$	$4.47^{a}\pm1.63$	$4.13^{a}\pm1.35$	2.415
Pb	$605.7^{a}\pm313.7$	$655.4^{a}\pm223.5$	$719.9^{a}\pm317.7$	0.238
Cu	$392.2^{b}\pm283.1$	$855.8^{a}\pm108.9$	$375.0^{b}\pm276.7$	10.655*
Cr	$214.7^{a}\pm29.4$	$119.4^{a}\pm72.7$	$179.7^{a}\pm27.7$	2.133
Cd	$433.4^{b}\pm223.4$	$707.8^{A}\pm130.3$	$428.7^{b}\pm302.8$	4.135*
Zn	$282.3^{a}\pm158.8$	$202.9^{a}\pm153.8$	$113.9^{a}\pm45.8$	1.963

Mean values with different letters along the same column are statistically different at 5% probability level.
± denotes standard deviation

Table 4. Nemerow Composite Pollution Index (P_s) of individual elements in the soils.

Axis	Pb	Cu	Cr	Cd	Zn	P_s
Eastern *Pi* (n=5)	7.46	6.23	3.15	305.88	1.41	221.1
Western *Pi* (n=9)	8.41	13.58	1.86	527.02	0.96	380.7
Southern *Pi* (n=6)	10.28	5.92	2.81	306.23	0.36	221.4
Ref (CCME, 2007) (mg/kg)	70	63	64	1.4	200	

Table 5. The single (E_r) and comprehensive (RI) potential ecological risk factors of heavy metals in the soils.

Axis	Single Potential Ecological Risk (E_r)					
	Pb	Cu	Cr	Cd	Zn	RI
Eastern	37.3	31.1	12.6	9176.4	1.4	9258.8
Western	42.0	67.9	7.4	15810.6	1.0	15928.9
Southern	51.4	29.8	11.2	9186.9	0.5	9279.8
Total [$\sum$(RI)/n] = 11,488.3						

The high RI of soils in this study has large potential to affect the ecological function of the study area. Cao et al. [10] asserted that metals in polluted soils have the potential to affect crops, and the effects could be observed directly or indirectly in humans that consume the crops. The tendency of these heavy metals to accumulate in crops planted around this study area is great because the studied heavy metals are reported to be active elements [39] with great affinity of accumulation in crops, and being translocated to the above-ground parts, making them available for transfer up the food chain.

Conclusions

This study concludes that the concentrations of Cd, Pb, and Cu in the soil of around Lafarge Cement WAPCO are results of cement production, including production processes, vehicular activities engaged in transport, and anthropogenic activities. These heavy metals, especially Cd, have great potential on the ecological function of the area. The high mobility of Cd coupled with its heavy load in the soil poses serious environmental concern.

Recommendations

- Due to the high contributing factor of Cd to the potential ecological risk of the area, intensive study should be conducted to determine the actual route of Cd introduction to the soil.
- Farming activities should be discouraged within a radius of 10 kilometers of the vicinity of the factory because there is every possibility of great uptake of these heavy metals by crops planted, which will eventually reach up the food chain to humans.

- Efforts should be made to bioremediate some metal contents of the soils, especially Cd, to reduce ecotoxicological problems.
- Monitoring and environmental audit of production by the designated authority in charge of the environment should spring into action to boast the environmental quality of this area.
- Further research should be carried out to determine the potential risk of these heavy metals to crops and humans in this area.

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