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Heavy Metals in the Soil Around a Cement Company in Sokoto, Northwestern Nigeria Pose Health Risks

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ABSTRACT: Cement is widely used in the building industry because it is reliable and because its basic ingredients are inexpensive and abundant. However, the production of cement produces heavy metal-laden dust that can harm humans and the environment. This study aimed to determine the risk posed by heavy metals in the soil around a cement company in Sokoto, Nigeria. Soil samples were obtained at 0.1, 0.5, and 1.0 km from the company and served as test samples, while control samples were obtained at 5.0 km away. The soil samples were treated and assayed for lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) using atomic absorption spectroscopy. The values obtained were used to estimate the heavy metals' average daily inhalation (ADI), average daily dermal exposure (ADDE), hazard quotient (HQ), health risk index (HRI), and carcinogenic risk (CR). Permissible levels of all the heavy metals were detected at all the locations (0.1 > 0.5 > 1.0 > 5.0 km). However, the ADI, ADDE, HQ, HRI, and CR of the heavy metals were above the permissible limits. It can be inferred from the results that the soil around the company can predispose humans to heavy metal toxicities. Consequently, the company needs to prioritize pollution control.

KEYWORDS: Cadmium; carcinogenic risk (CR); hazard quotient (HQ); heavy metals; lead.

1. Introduction

Cement is widely used for building infrastructures such as houses, highways, bridges, embankments, offices, and flyovers, among others, which has led to a surge in its production worldwide [1, 2]. As of 2021, global cement production has reached 2.1 billion tons and is expected to increase to about 3.0 billion tons by 2030, representing a 4% increase over the years [3]. In West Africa, Nigeria produces the largest volume of cement, with an annual production of 58.9 million metric tons [1]. To meet up with the increasing demands, Nigeria's cement industry employs several categories of workers and thus contributes significantly to the nation's economy. Moreover, the block-making industry, whose major raw material is cement, employs about 10 million people in Nigeria [4]. In Asian countries, particularly Bangladesh, the cement industry grew at almost 11.5% per annum due to the increasing demand for cement from 14.5 million metric tons per year to almost 31 million metric tons per year [5]. Higher demands for cement in Africa and Asia are expected in the future because the continents have been projected to experience high population expansion [6]. Cement is widely used because it is readily available, durable, reliable, and affordable compared to other binders [7, 8].

Unfortunately, cement manufacturing is one of the most polluting activities, emitting toxic dust and gases into the atmosphere. Cement production is responsible for about 7% of the greenhouse gases emitted worldwide through its carbon dioxide emissions [9, 10]. Moreover, the primary constituents of cement, such as silicon dioxide, calcium oxide, iron oxide, and aluminum trioxide, can induce toxic effects [11]. Cement production processes also give off pollutants such as dioxin, heavy metals, and particulate matter [12]. Among the mentioned pollutants, heavy metals are the most frequently implicated and researched in environmental toxicity because of their persistency and non-biodegradability. Heavy metals are dense, and most of them can be harmful at low levels. Heavy metals can generate reactive oxygen species, which in turn produce oxidative stress that damages cells, DNA, tissues, and organs. Commonly found heavy metals in cement dust include chromium, lead, zinc, copper, nickel, cobalt, lead, and mercury [13, 14].

Given the foregoing, periodic pollution monitoring at cement plants is required to protect the health of workers and residents living near cement plants. This will create a sustainable development where the cement industry grows unhindered and the health of workers and locals is not jeopardized. A few studies have been conducted on heavy metal pollution by cement plants in Sokoto, Nigeria, but there is a dearth of documented information on the potential health hazards of heavy metals in the soil around cement plants in the city. This study, therefore, evaluated the levels and risks posed by heavy metals in soil around the vicinity of a cement company in Sokoto, Nigeria.

2. Materials and Methods

2.1. Description of the study area.

This study was conducted in the Kalambaina area in Wamakko, Sokoto State, Nigeria. Wamakko town is located approximately 12 km west of Sokoto city, between latitude 13° 2' 16" N and longitude 5° 5' 37" E (Figure 1). Sokoto State is situated at the far end of northwestern Nigeria, close to the meeting point of the Rima River and the Sokoto River. Sokoto State covers an area of about 25,973 km^2, of which the Niger Republic and Benin Republic border the state in the north and west, respectively. The state also borders Birnin Kebbi and Zamfara States in the west and east, respectively. The indigenous people of the state are Hausa/Fulani by tribe and are predominantly cereal and animal farmers. Sokoto State is in the savannah zone, characterized mainly by grasses and shrubs, with an annual rainfall of between 500 mm and 1,300 mm, which starts late and ends early. Sokoto State is one of the hottest places in Nigeria, with temperatures that can rise above 40 °C during the hot season and fall below 20 °C during the harmattan. Sokoto State has over 101 million tons of limestone deposits in the Kalambaina area [15]. The quarrying of limestone and operations at the cement company could potentially pollute the environment. Hence, the need for the present study.

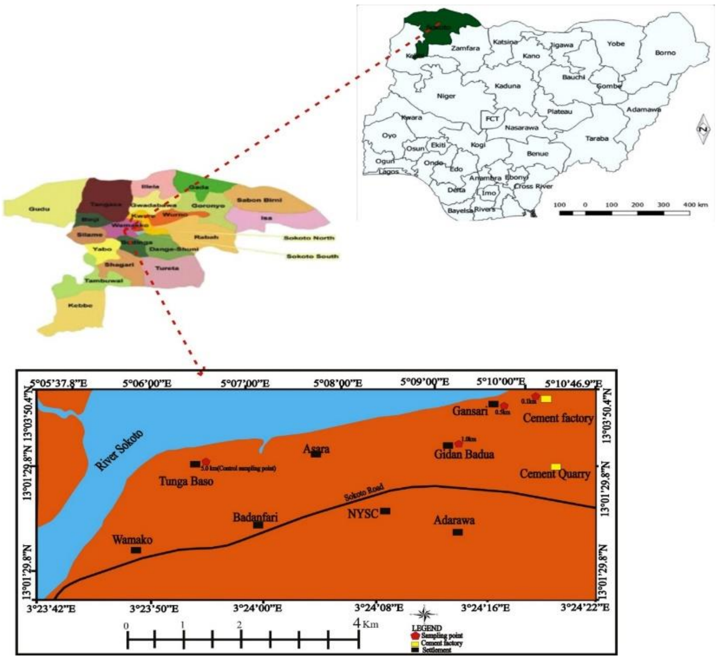

Figure 1. Locations of the study area.

2.2. Soil samples collection and preparation.

Triplicate soil samples were collected in dry, pre-cleaned bottles at distances of 0.1, 0.5, 1.0, and 5.0 km from a cement company in Wammako in December 2021. The sample bottles were labeled and carried in a polyethylene bag to the laboratory. The samples were shade-dried for 5 days before being oven-dried completely. The samples were milled into powder with a mortar and pestle and homogenized.

2.3. Heavy metal analysis.

Heavy metals in the soil samples were analyzed following the procedure used by Yahaya et al. [16]. One gram (1 g) of an individual soil sample was digested in a beaker containing 10 ml each of nitric and perchloric acids and 1 ml of sulphuric acid. After stirring for a few minutes, distilled water (5 ml) was added and stirred again. The digest was filtered into a volumetric flask (50 ml), and distilled water was used to top up the solution to the meniscus level. The PG-990 atomic absorption spectrophotometer was employed to quantify the levels of cadmium (Cd), zinc (Zn), lead (Pb), and copper (Cu) in each solution.

2.4. Health risk assessment.

2.4.1. Non-carcinogenic risks

The non-carcinogenic risks of the heavy metals were calculated from their average daily inhalation (ADI), average daily dermal exposure (ADDE), hazard quotient (HQ), and health risk index (HRI) as shown in equations 1, 2, 3, and 4 [16].

$$ADI = \frac{\mathrm{CoH} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{ABW} \times \mathrm{AT}} \quad (1)$$

$$ADDE = \frac{CoH \times ESSA \times AF \times DAF \times EF \times ED}{ABW \times AT} \quad (2)$$

$$HQ = \frac{ADI/ADDE}{RFD} \quad (3)$$

$$HRI = \sum HQ \text{ of individual heavy metals} \quad (4)$$

Note: CoH is the concentrations of heavy metals in the soil; IR denotes inhalation rates of soil = 16; EF represents the exposure frequency (days/year) = 365; ED means the exposure duration (year) = 24; ESSA stands for the exposed skin surface area (cm^2), which is 5700; AF is the adherence factor (kg/m^2/day) = 0.07; ABW is the average body weight (kg) = 65; AT is the average time (day) = ED x 365. DAF is the dermal absorption factor, and it equals 0.14 for Cd, 0.1 for Cu, 0.02 for Zn, and 0.006 for Pb. RFD means reference dose, of which the oral/dermal RFD of Pb is 0.00014/0.00014, Cd is 0.001/0.000025, Zn is 0.3/0.3, and Cu is 0.04/0.04.

2.4.2. Carcinogenic risks.

The carcinogenic risks (*CR*) of heavy metals were calculated using equation 5 [16].

$$CR = ADI/ADDE \times CSF \quad (5)$$

Note: *CSF* represents the cancer slope factor (mg/kg/day), of which Pb is 0.009, Cd is 6.3, Cu is 0.00, and Zn is 0.00. A substance is considered carcinogenic if its CR is greater than 10^{-6}.

2.5. Data analysis.

Values were presented as mean ± standard deviation (SD) using the Statistical Package for Social Sciences version 21. To compare statistical differences between the control and test groups, the *f*-test (ANOVA) was used, with $p \leq 0.05$ considered statistically significant.

3. Results and Discussion

3.1. Levels of heavy metals in the soil samples.

Table 1 shows the levels of Zn, Cd, Cu, and Pb in the soil samples obtained at distances of 0.1, 0.5, and 1.0 km from the cement company and at a distance of 5.0 km (control) from the company. All the soil samples contained permissible limits of the evaluated heavy metals based on the standard set by the World Health Organization (WHO). Significant differences did not exist ($p > 0.05$) between the soil samples obtained at 0.1 and 0.5 km, but they existed ($p < 0.05$) between the mentioned locations (0.1 and 0.5 km) and those obtained at 1.0 km. Furthermore, there were significant differences ($p < 0.05$) between soil samples collected at 5 km (the control) and all other locations, which suggests that the company is impacting the environment negatively. On average, Zn was the most abundant in the soil samples, followed by Cu, Pb, and Cd. Ordinarily, Zn, Cd, Cu, and Pb are not basic constituents of cement, but they can be introduced through the burning of tires as supplementary fuel in cement factories [9]. Moreover, cement has the ability to bind and retain Pb, Cu, Ni, and Zn, which could explain why the heavy metals were detected in the cement-polluted soil [14].

The results obtained are consistent with those of Laniyan and Adewumi [17], who reported permissible levels of heavy metals in soil samples obtained around a cement company in Ewekoro, Ogun State, Nigeria. Adejoh [18] also reported permissible levels of heavy metals in soil samples obtained from the vicinity of a cement plant in Obajana, Kogi State, Nigeria. Moreover, Yitagesu and Bekele [19] reported permissible levels of heavy metals in soils around a cement factory in Abyssinia, Ethiopia. However, the results contradict those of Olatunde et al. [20], who reported non-tolerable levels of heavy metals in soil samples obtained from a cement plant in Ibeshe, Ogun State, Nigeria. Ujoh and Alhasan [21] also reported non-permissible levels of some heavy metals in soil samples obtained from a cement plant in Gboko, Benue State, Nigeria. Moderate to severe enrichment of heavy metals in soils around a cement plant in Shiraz, Iran, was also reported by Amiri et al. [22]. Pollution control facilities, the technology used (whether it's old or new), policies, and whether or not pollution control measures are followed vary a lot. This could be why the results of the studies listed above are not consistent.

Table 1. Mean levels of heavy metals in soil samples obtained from a Cement Company in Sokoto, Nigeria.

Distance (km)	Zn (mg/kg)	Cd (mg/kg	Cu (mg/kg)	Pb (mg/kg)
0.1	5.88 ± 0.13^{a}	0.05 ± 0.01^{a}	0.84 ± 0.07^{a}	0.48 ± 0.02^{a}
0.5	5.28 ± 0.16^{a}	0.06 ± 0.01^{a}	1.04 ± 0.02^{a}	0.50 ± 0.06^{a}
1.0	1.49 ± 0.01^{b}	0.05 ± 0.01^{a}	6.39 ± 0.06^{b}	0.15 ± 0.01^{b}
5.0	1.53 ± 0.01^{b}	0.01 ± 0.00^{b}	0.73 ± 0.01^{a}	0.39 ± 0.01^{b}
Limit [23]	60	0.8	36	85

Values with different superscripts along the column are significant different at $p \leq 0.05$ (ANOVA)

3.2. Non-carcinogenic risks of the heavy metals

The average daily inhalation (ADI) of heavy metals from the soil samples is shown in Table 2. All the soil samples contained non-permissible respirable Pb, except those obtained at a distance of 1.0 km from the company. The soils obtained at 0.1, 0.5, and 1.0 km contained non-permissible respirable Cd, while the soil samples obtained at 5.0 km were within the permissible limits. The soil samples obtained at 1.0 km contained non-permissible respirable Cu, while other locations were within the permissible range. All the soil samples contained permissible respirable Zn. On average, the soil samples collected at 0.1, 0.5, and 1.0 km contained higher levels of respirable heavy metals than those collected at 5.0 km.

Table 2. Average daily inhalation (ADI) of heavy metals in soil samples obtained from a cement company in Sokoto.

Distance (km)	Zn (mg/m^3)	Cd (mg/m^3)	Cu (mg/m^3)	Pb (mg/m^3)
0.1	1.447	0.012	0.207	0.143
0.5	1.299	0.018	0.256	0.123
1.0	0.367	0.012	1.572	0.037
5.0	0.377	0.002	0.179	0.096
Limit [34]	2.0	0.002	1.0	0.05

Table 3 shows the average daily dermal exposure (ADDE) to heavy metals in the soil samples. Dermal exposure to Zn was beyond the tolerable limits at 0.1 and 0.5 km but not at 1.0 and 5.0 km. Dermal exposure to Cd was beyond the recommended limits at all the locations except 5.0 km. Cu was within the recommended limits, except in the soils obtained at 1.0 km. Dermal exposure to Pb exceeded the tolerable limits, with the exception of soils collected at 1.0 km. On average, dermal exposures to the heavy metals were higher in the vicinity of the cement company (0.1, 0.5, and 1.0 km) compared to the control (5.0 km).

Table 3. Average daily dermal exposure (ADDE) to heavy metals in soil samples obtained from a cement company in Sokoto.

Distance (km)	Zn (mg/kg)	Cd (mg/kg	Cu (mg/kg)	Pb (mg/kg)
0.1	10.312	0.614	7.366	0.253
0.5	9.260	0.737	9.120	0.263
1.0	2.613	0.614	56.035	0.079
5.0	2.683	0.123	6.402	0.205
Limit [34]	5.0	0.01	1.0	0.05

The hazard quotient (HQ) and health risk index (HRI) of the heavy metals in the soil samples are depicted in Table 4. All of the heavy metals in the soil samples obtained from all of the locations were above the recommended limits (> 1) for HQ and HRI. To sum it up, the results of the noncarcinogenic risk assessment further proved that the heavy metals in the soil samples can cause adverse effects on humans. Chronic human exposure to Cd through air or dermal contact can cause systemic damage, such as damage to the urinary, respiratory, nervous, skeletal, reproductive, and cardiovascular systems [24, 25]. Acute or chronic Cu exposure can cause mental retardation in children, severe hematological and kidney damage, and asymptomatic cerebral ischemic stroke [26, 27]. Excessive Pb exposure is capable of causing mental, urinary, respiratory, and heart problems via immune dysfunction, oxidative stress, and an inflammatory response [28]. In most cases, dermal exposure to Zn does not cause any serious health hazards [29]. However, acute exposure to respirable Zn can cause "fume fever" (a flu-like illness), while chronic exposure can impair lung function and aggravate asthma [30]. Interestingly, average inhalation of Pb and dermal contact with Cd, Cu, and Pb at 5.0 km (the control) were higher than permissible limits, indicating that the environment around Sokoto is generally polluted and that the cement company under study only worsens the pollution levels. The results of the current study are in line with those of Yahaya and Okpuzor [31], who reported non-tolerable and increasing levels of exposure to heavy metals with proximity to a cement factory in Sagamu, Ogun State, Nigeria. Moreover, Warrah et al. [32] reported increasing and non-tolerable concentrations of heavy metals in plants with increasing proximity to a cement company in Sokoto, Nigeria. Similarly, Idris et al. [33] reported non-tolerable levels of Pb and Cd as well as hematological abnormalities in blood samples of animals raised around a cement plant in Sokoto, compared to a control site.

Table 4. Hazard quotient (HQ) and health risk index (HRI) via inhalation (IH) and dermal contact (DC) with heavy metals in soil samples obtained from a cement company in Sokoto.

Distance (km)	Zn		Cd		Cu		Pb		*HRI*	
	IH	DC	IH	DC	IH	DC	IH	DC	IH	DC
0.1	4.82	34.37	12.0	24.56	5.18	184.2	1021.4	1807.1	1,043.4	1,264.5
0.5	4.33	30.87	18.0	29,480	6.40	228.0	878.57	1,878.6	907.3	31,977.5
1.0	1.22	8.71	12.0	24,560	39.3	1,400.8	264.29	564.29	316.81	26,533.8
5.0	1.26	8.94	2.0	4,920	4.48	160.05	685.71	1,464.3	693.45	6,553.3

Note: IH represents inhalation; DC represents dermal contact; HRI represents health risk index (summation of IH and DC of all the heavy metals at each location).

3.3. Carcinogenic risks of the heavy metals.

The carcinogenic risk (CR) of carcinogenic heavy metals (Cd and Pb) in the soil samples is revealed in Table 5. The *CR* of the heavy metals mentioned via inhalation and dermal exposure was higher than the recommended limits (10^{-6}). This further proved that operations at the cement company may have adverse effects on humans. Most heavy metals induce carcinogenesis through diverse and complex mechanisms [35, 36]. For instance, Cd induces cancer by inhibiting tumor-suppressing genes, disrupting DNA repairs, stimulating cell growth, and suppressing apoptotic pathways in tumor cells [37]. Pb triggers oxidative stress and increases the susceptibility of genes to oxidative stress, raising estrogen levels, which is a risk factor for breast cancer [37]. Cu and Zn are non-carcinogens and do not pose any carcinogenic risk. The findings of the current study are consistent with those of Ogunkunle et al. [38], who reported a health risk of heavy metals in soil samples obtained from the vicinity of a cement plant in Sagamu, Nigeria. Egbe et al. [39] also reported a health risk of heavy metals in soils around a cement plant in Cross River State, Nigeria. In the same vein, Laniyan and Adewumu [17] reported an ecological risk of heavy metals in plants around Ewekoro cement in Ogun State. Contrarily, Kolo et al. [40] reported safe carcinogenic and non-carcinogenic values of heavy metals in soils obtained around a cement plant in Gombe State, Nigeria. Moreover, Jafari et al. [41] reported a non-health risk of heavy metals in soil samples obtained on the premises of a cement plant in Douroud, Iran. As was already said, these differences could be because the companies in question use different pollution control methods, have different facilities, or differ in their compliance with environmental safety rules.

Table 5. Carcinogenic risk (CR) via inhalation (IH) and dermal contact (DC) of heavy metals in soil samples obtained from a cement company in Sokoto.

Distance (km)	Zn		Cd		Cu		Pb	
	IH	DC	IH	DC	IH	DC	IH	DC
0.1	0.00	0.00	0.076	3.868	0.00	0.00	0.001	0.002
0.5	0.00	0.00	0.113	4.643	0.00	0.00	0.001	0.002
1.0	0.00	0.00	0.076	3.868	0.00	0.00	0.003	0.001
5.0	0.00	0.00	0.013	0.775	0.00	0.00	0.001	0.002
Permissible limit $<10^{-6}$								

4. Conclusions

The soils within or close to the vicinity (distances of 0.1, 0.5, and 1.0 km) of the cement company contained permissible levels of Cu, Zn, Pb, and Cd, but long-term exposure to the soil can induce health hazards, as revealed by the health risk assessment. This suggests that operations at the factory may have adverse effects on humans and the environment with regard to the heavy metals evaluated. The heavy metals in the soils at the control site also posed some health risks, indicating that the environment surrounding Sokoto is generally polluted, but the cement operations only exacerbate it. Workers are advised to practice personal hygiene, always wear protective gear, never allow cement or soil to remain on their bodies for an extended period of time, and do constant medical checks to detect early signs of exposure. The management should prioritize pollution control and hire workers on a shift basis in order to reduce work hours and exposure duration. People are advised not to reside close to cement plants. One limitation of this study is that it does not evaluate all heavy metals, which could have provided more convincing results. Therefore, we recommend more studies to ascertain our claims and cover more heavy metals or trace metals not evaluated in the current study.

Abbreviation

ABW : average body weight.
ADI : average daily inhalation.
ADDE : average daily dermal exposure.
AF : adherence factor.
AT : average time.
CSF : cancer slope factor.
CR : carcinogenic risks.
CoH : concentration of heavy metal.
DAF : dermal absorption factor.
ED : exposure duration.
HQ : hazard quotient.
HRI : health risk index.

IR : inhalation rate.
RFD : reference dose.

Acknowledgments

Not applicable.

Competing Interest

All authors have no competing interest to declare.

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