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Research Article

Dust Deposition and Associated Heavy Metal Contamination in the Neighborhood of a Cement Production Plant at Konongo, Ghana

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The release of harmful particles from industries is one of the important sources of environmental pollution worldwide. The goal of this study was to determine the amounts of dust deposition and heavy metal pollution in the soils surrounding a cement mill in Konongo, Ghana. Topsoils (0-10 cm) were sampled at the four geographical axes of the factory within a radius of 400 m, while at the same time, about 500 g of cement was sampled with a hand trowel. A Frisbee dust sampler was used to examine the levels of dust depositions at the various geographical axes of the factory. The heavy metals such as cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), and lead (Pb) were measured in a total of 20 soil samples using atomic absorption spectroscopy (AAS). The results obtained for climatic elements such as wind speed and direction, temperature, and relative humidity were 2.25, 25.7, and 49.5 m^3/s, respectively. The average deposition of dust within the study period using the geographical axis indicated that the southern axis recorded the highest dust accumulation with a mean of 60.2 g/m^2 per month. The mean concentrations of metals at the various axes were 1.04 mg/kg, 4.78 mg/kg, 8.95 mg/kg, 9.30 mg/kg, and 18.4 mg/kg for Cd, Cr, Cu, Zn, and Pb, respectively. The concentration of chemical components investigated in the soil was below the WHO/FAO standard, except for Cd. The spatial distribution pattern of the examined heavy metals showed that Cd, Cr, and Cu represent possible sources of soil contaminants. According to the conclusions of this research, this paper suggests an approach to investigate the areas contaminated with heavy metals to call out the attention of local authorities to take action.

1. Introduction

Cement manufacturing is one of Ghana's most rapidly expanding businesses. Because cement consumption and economic growth are intimately intertwined, it plays a key role in the development of the country's infrastructure. Despite its prosperity, the business confronts numerous obstacles related to environmental concerns and long-term viability [1]. Although the pollution caused by the cement industry has never been disputed, the extent to which it hurts the environment is unknown. The cement industry's most apparent pollution is dust, which comes primarily from kiln stacks in cement manufacture [2]. Wind, rain, and other dispersal processes disperse the cement dust over broad areas. The alkalization of the environment and changes in the chemical makeup of the soil, air, water, and vegetation are direct repercussions of cement dust pollution [3]. Due to stomata blockage, gaseous exchange, and a decreased rate of transpiration, cement dust affects crop output. By immediately covering the leaf surface, the dust also hinders intercellular functions and changes plant biodiversity [4]. Bilen [5] reported that human health is harmed by cement dust accumulating in and on plants, animals, and soils. The distribution of particle deposition in different parts of the respiratory tract influences the health concerns caused by inhaled dust particles. This can lead to respiratory difficulty or failure [6].

Furthermore, Shukla et al. [7] reported that heavy metals such as chromium, nickel, cobalt, lead, and mercury can be found in cement dust, posing a threat to the biosphere. These dangerous substances have an impact on flora, human and animal health, and the environment as a whole. The US Environmental Protection Agency and the International Agency for Research on Cancer (IARC) have classed metals as human carcinogens since they are known to cause various harmful effects to human organs even at low levels of exposure. Plant growth and development are influenced by the presence of heavy metals in higher concentrations in soil. It can cause plants to die by interfering with their physiological and metabolic activities [8, 9]. Pereira et al. [10] concluded that cattle raised in Spain on Ni-rich soils accumulated hazardous levels of the metal in their kidneys. Cu was also found in their livers, demonstrating that contaminated places can introduce dangerous levels of metals into the food chain. Zhao et al. [11] indicated that heavy metal toxicity in people and animals can result in acute and chronic illnesses, as well as death when high quantities of heavy metals are present in food crops and plants.

Deficiencies in environmental performance monitoring and industry compliance have been exploited by some plant operators in Ghana. As a result, the harmful effects of such industrial activities are threatening various host populations and their environments. Because each cement emission is unique, studies on numerous cement facilities in various areas throughout the world should be conducted locally [12]. This study is necessary to investigate environmental concerns of the company's operation against which neighboring communities of the cement factory had protested possible farmland destruction, emission of cement dust, and contamination of the Anuruso stream (public perception) before its establishment. Continuous environmental monitoring is still an important tool for evaluating the performance and environmental compliance of cement plants, especially in light of new allegations of high pollution levels related to the cement sector [13]. This is significant because, in Ghana, there is a clear legal need to follow the rules. In order to create baseline data and information for future referencing and comparison research, the project aims to assess the environmental impact of dust emissions and subsequent heavy metal dispersion in the immediate vicinity of the cement production plant in Konongo.

2. Materials and Methods

2.1. Demographic, Economic Activities, and Geology of the Study Area. The study was undertaken in Konongo, the capital of Asante Akim Central Municipal in the Asante Region of Ghana. It is located at latitudes 60 30′ *N* and 70 30′ *N* and longitudes of 00 15′ *W* and 10 20′ *W* [14]. The population of the municipality is 71,508 comprising 33,942 men (47.5%) and 37,566 women (52.5%), for a sex ratio of 90.4. This means that there are around 90 males for every 100 females in the municipality. The municipality's population is young (39.2%), displaying a broad base population pyramid that tapers off with a tiny proportion of the elderly (5.2%). The municipality's total age dependency ratio is 79.8, and males have a greater age dependency ratio (84.6) than females (75.7) [15]. In economic activities, 92.7 percent of the economically active population is employed, with 7.3 percent unemployed [15]. The majority of those who are economically inactive are students (46.5%), while 25.6 percent perform household duties and 5.4 percent are disabled or too sick to work. Approximately 66.0 percent of unemployed people are looking for jobs for the first time [15].

The community's main source of employment is agriculture. Their produce comprises food and vegetable crops such as cassava, grains, tomatoes, and garden eggs [16]. The area also grows a lot of cash crops like cocoa, oil palm, and oranges [15] as the soil is rich in organic matter and nutrients, and the weather is pleasant all year [16]. This combination results in the generation of substantially above normal agricultural yields. However, several industrial activities are going on in the municipality such as the cement and agro-based operations which deposit harmful chemical constituents into the atmosphere and could highly affect the rich soil which supports agricultural production. The cement-producing factory has been in existence since 2015. This, in the long run, can be a threat to human health considering its implications on the food chain.

In terms of the geology of the area, the series includes rocks from the Upper Birimian Series and Tarkwaian System within the Konongo Project area [17]. The Tarkwaian rocks are found as an infolded synclinal formation that is bordered by the Upper Birimian to the northwest and southeast. The Upper Birimian is thought to be represented by the sequence in the northern portion of the tenement, which is best exposed at the Kwakawkaw mine through mining and exploration. Mining and exploration at Konongo have provided information about the succession in the southwest portion of the tenement. The rocks are overfolded, strike northeasterly, and dip sharply to the northwest [17].

2.2. Sampling Design and Preparation. The sampling of the soil samples at the study site followed a modified approach adopted in reference [18]. In the immediate vicinity of the cement factory, soil samples were taken. The cardinal directions of north, south, east, and west were set as reference points for our sampling locations. The rationale for using the cardinal directions of dust sampling is to capture the variability of dust concentrations in the given area [19]. These locations were 100 m away from each other as shown in Figure 1. Five spots were identified randomly at each site, and a mini pit was dug 10 cm using a soil auger to sample the soil. Soils were sampled up to 10 cm in depth due to the rocky nature of the sampling area. A total of 20 points were dug, and the sampled soils were placed in well-labeled containers. At each sampling point, the Global Positioning System (GPS) coordinates were taken. The samples of soil were transported to the laboratory for further processing. Three days of air drying were done on soil samples. The soil samples were air-dried for three days to obtain dry weight and homogeneity, pulverized, and sieved using 0.4 μm mesh, which was similar to a study reported by Dierig [20]. The 0.4 μm mesh size ensures the removal of high solids while producing finer particle sizes for further study.

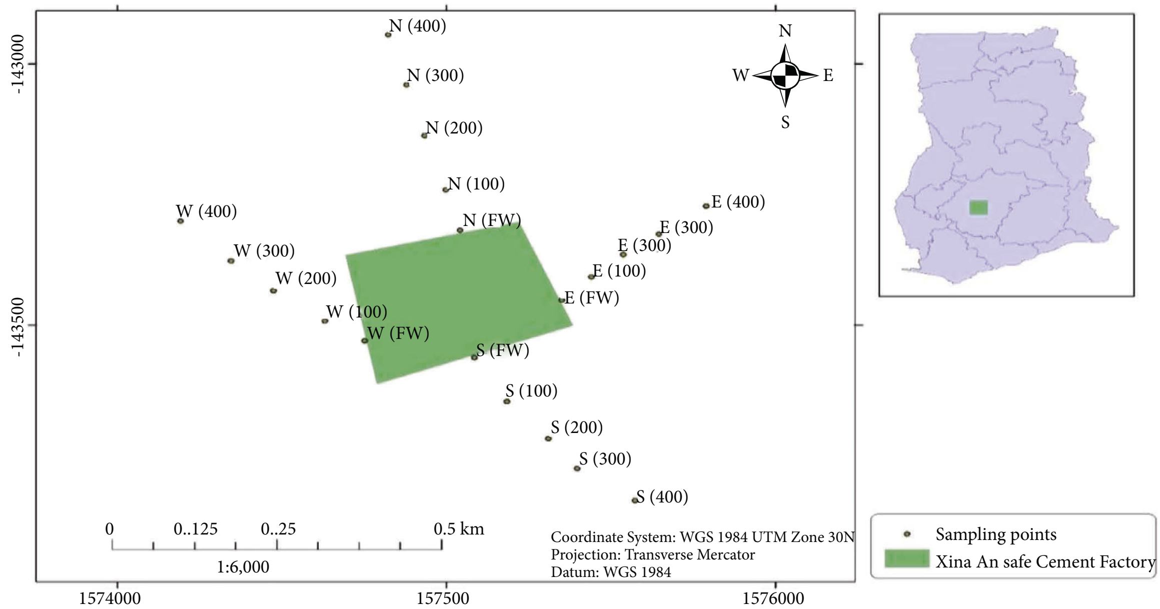


Figure 1: Map of sampling sites.

(a) (b)

Figure 2: (a) Frisbee dust sampler mounted at 100 m away from the north axis. (b) Frisbee dust sampler at 200 m away from the east axis.

500 g of cement was scooped from the cement production plant using a hand trowel. The sample was transported to the laboratory for chemical analysis.

Dust samples were collected according to a modified technique prescribed by Mohamed et al. The dust samples were gathered from the same areas as the soil samples. The sample collection stations were chosen such that they are 100 m apart. Sampling was done in open regions away from buildings taller than 20 m. Stations were also far away from local sources of pollution and at easily accessible spots. The dust samples were collected using a Frisbee dust sampler (SEI-Y 23 series–Cyberscan, UK) of 133 mm diameter and 25 mm depth which was fixed on a vertical stand of about 1 m to prevent the entry of terrestrial dust from contaminating the dust sample (Figure 2). The stations were checked randomly for bird droppings which could affect the samples. The readings for daily measurements from the gauge were taken on-site for a period of thirty days (November to December 2020). It is worth noting that the readings only represent dry deposition because there was no rain throughout the collection period.

2.3. Analysis of the Toxicants. The chemical analysis followed a modified protocol adopted by Baah et al. [21]. About 2 g of the air-dried portions of the soil samples was digested in aqua regia ($HCl : HNO_3 = 3 : 1$) at 100°C for 1 h using the Teflon microwave digestion vessel. The samples were then left to cool, after which they were decanted after some 30 minutes. The trace metals in the solutions were analysed using the Atomic Absorption Spectrometer (AAS) SPECTRA AA 220 Air-acetylene Flame. The results were recorded in mg/kg dry weight and the duplicate samples were compared. The results of the samples in each batch were

Table 1: Summary of the mean weather condition data around the factory.

Week	Mean wind speed (m/s)	General wind direction	Temperature (°C)	Mean relative humidity (%)
1	2.11	SW	25.8	44.0
2	2.24	SW	25.6	39.0
3	2.44	SW	24.7	57.0
4	2.23	SW	26.8	58.0
Mean	2.26	SW	25.7	49.5

consolidated by averaging the values per sampling event and recorded for all 4 sites using the approach adopted by Foli et al. [22].

For every metal that was examined in this investigation, blank solutions were made. Before analyzing the samples for the selected toxicant, the blank solution for each metal was examined first. The source of the blank solution for each specific toxicant in this study was all the chemicals employed in the digestion procedure minus the sample; the blanks were made in the same manner as the samples. The real concentration of the specific metal was then calculated by subtracting the blank concentration from the metal concentration in the sample.

2.4. Spatial Analysis of Heavy Metal Concentrations with Geographical Information System (GIS). Heavy metal concentration spatial distribution maps are a valuable tool for delineating safe and unsafe zones, as well as identifying hotspots with high metal concentration zones in a region that needs to be studied [23]. The inverse distance weighted approach was used to perform geo-statistics interpolation in Arc GIS (Environmental System Research Institute (ESRI) version 10.4.1). The inverse of the distance raised to a mathematical power, which controls the significance of known points on the interpolated values based on their distance from the output points, is used in this method, which assumes that the influence of the variable being mapped decreases with distance from its sampled location [24].

2.5. Data Analysis. The results of the investigation were presented as a mean and standard deviation. After that, a one-way analysis of variance (ANOVA) was used to rank and compare means at a 5% level of significance. For all statistical studies, SPSS software version 20.1 was utilized. The heavy metal concentrations were also utilized as input data for soil contamination maps to explore the spread of heavy metals in the soil surrounding cement manufacture.

Principal component analysis (PCA) was used with factor extraction with an eigenvalue greater than one (>1) following varimax rotation to determine the association of metals, which aids in the transmission of information about the source and spread of heavy metal contamination. The rotation of the principal component was accomplished using the varimax approach, and the factor loadings obtained by PCA with varimax were performed for numerous heavy metals.

Table 2: Dust loads at various distances on the study site at the four geographic locations.

Distance (m)	Dust load (mg/m^2/day)			
	NA	EA	SA	WA
100	42.36	43.75	59.88	48.41
200	40.62	45.62	61.34	50.57
300	39.02	41.84	59.62	50.83
400	35.69	42.90	59.91	51.74
Mean	39.4	43.5	60.2	50.4
SD	2.38	1.60	0.78	1.41

SD = standard deviation; NA =north axis; EA = east axis; SA = south axis; WA = west axis.

3. Results and Discussion

3.1. Meteorological Data. The prevailing meteorological data during the study are shown in Table 1. The temperature ranged from 24.7 to 26.8°C with an average value of 25.7°C. The relative humidity ranged between 39 and 58% with an average value of 49.5%. The wind blew constantly in the south-westerly direction with an average speed of 2.26 m/s. The temperature variations observed were minimal as seen in Table 1 and therefore had little or no effect on the distribution of dust. The distribution of dust is strongly influenced by relative humidity (RH) [25–27]. The hygroscopic materials in the dust particles attract water, causing particles to settle down more quickly from the source. However, Howell et al. [28] indicated that relative humidity is a complicating factor when trying to characterize the distribution of dust. The weather conditions for November and December are a relatively stable and dry windy season with intermittent rainfall. Depending on the prevalent weather conditions, the dust deposition may exhibit a seasonal pattern of variation whenever these weather parameters change. However, Tunckaya [29] and Roy et al. [30] emphasized that wind speed and direction play important roles in the transport and deposition of dust particles and also in generating fugitive dust, especially around industrial activities.

3.2. Dust Distribution and Point Sources around Cement Plant. The dust load data show a significant abundance of dust in the surrounding environment of the factory. Table 2 shows the dust distribution records on-site at the four geographical locations. Their mean values from five different samples are presented as shown in Figure 3.

The northerly axis (NA) recorded dust deposition rates with a minimum of 35.69 mg/m^2/day, a maximum of 42.36 mg/m^2/day, and a mean of 39.23 mg/m^2/day. Also,

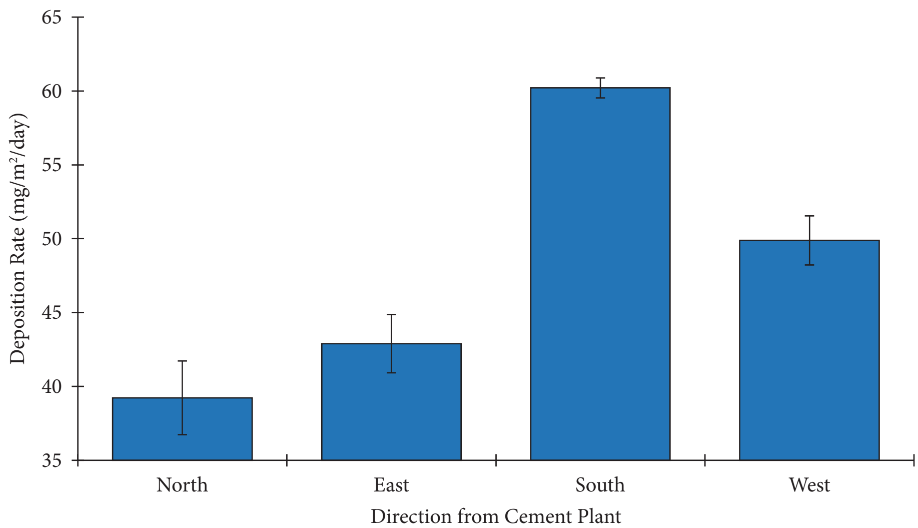


Figure 3: Dust load in varying directions from the cement plant.

Table 3: Major dust emitting sources of the cement manufacturing building.

Installed stacks	Source classification	Outlet	Height (m)
Raw mill and kiln	Point source	Stack outlet	86
Cooler clinker	Point source	Stack outlet	55
Cement mill	Volume source	Open outlet	—

deposition rates of 45.62 mg/m^2/day and 40.38 mg/m^2/day were recorded along the easterly axis (EA) for the highest and the lowest deposition, respectively, with a mean of 42.90 mg/m^2/day. On the southerly axis (SA), 61.34 mg/m^2/day and 59.62 mg/m^2/day, respectively, were recorded for the maximum and minimum deposition rates. Again, deposition rates of 51.74 mg/m^2/day and 47.87 mg/m^2/day were, respectively, recorded as the highest and the lowest deposition rates on the westerly axis (WA) with an average of 49.88 mg/m^2/day.

The results from the dust load show that dust emanates in all directions away from the cement plant (Figure 3). This indicates the aerial distribution of the dust from the factory's dust stack. The highest level of dust load was observed in the southern direction of the plant. The high accumulation of dust recorded in the southern direction can be attributed to the presence of production activities such as the kiln operations at the southern part of the cement factory which invariably have increased the quantity of the dust in this direction. Also, the disparities in the dust accumulation values recorded at various stations can be ascribed to the prevalent wind flow direction along with the sampling stations within the cement production plant. A similar observation was reported by Norman [31] in their publication on Jaypee Rewa Cement Factory in North India.

Table 3 presents a summary of the major sources and classification of dust emission outlets from the cement manufacturing building. The installed stacks, raw material storage, and the loading area for products at different units of the cement facility influenced the distribution of the dust particles at the various axes of the cement plant. However, the largest emission source is from the kiln operation and hauling systems. Higher levels of dust load were observed at the southern axis of the plant. This could be attributed to the presence of the kiln stack at this location.

Besides the dust emission from the installed stacks, some gases such as SO_2, NO_x, and CO_2 exited from the raw mill and kiln stacks. Concerning distance, it was discovered that the deposition of the dust increased from 100 m distance to 300 m distance on the north, east, and south axes and decreased at the 400 m distance on the west axes (Table 2). It was observed that the highest deposition load was recorded on the south axes (61 mg/m^2/day) at a 200 m distance. However, among the axes, the north received the least dust deposition load. The increased rate of dust deposition loads from 100 m to 300 m could be ascribed to the height at which the dust is liberated [32]. The decrease in dust deposition load at the 400 m distance could be associated with reduced air pressure which may affect the settling velocity to some extent [33]. This observation is consistent with the findings of Gbadebo and Bankole [34] in a study carried out around Sagamu Cement Factory in Nigeria. They observed that the air-borne time, particle distribution, and mobility of the dust particles around the Sagamu Cement Factory contributed to the particles settling down at distances close to the main source.

3.3. Heavy Metal Concentration in Cement. Figure 4 presents the heavy metal concentrations in cement produced at the cement production plant. The concentrations of heavy metals in the cement increased in the order of Cd < Cr < Cu < Pb < Zn. The concentrations of heavy metals in cement have been reported to be factory-dependent based on the raw materials used by Adeyanju and Okeke [35]. From a comparative assessment, higher amounts of these metals were reported in Diamond Cement than those

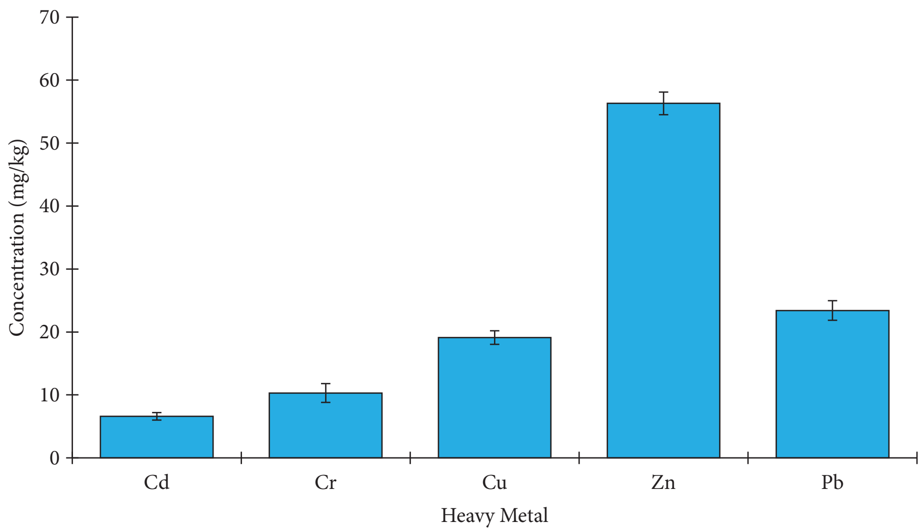


Figure 4: Concentrations of heavy metals in cement.

Table 4: Concentrations of heavy metals in soil samples.

Site ID	Concentration of heavy metals (mg/kg)				
	Cd	Cr	Cu	Zn	Pb
NA	1.03 ± 0.09	5.02 ± 0.25	8.84 ± 2.63	12.3 ± 4.37	17.6 ± 2.53
EA	1.06 ± 0.06	3.87 ± 1.67	10.3 ± 1.55	8.95 ± 1.10	17.6 ± 0.45
SA	1.07 ± 0.16	4.90 ± 0.89	12.0 ± 0.37	12.9 ± 3.32	25.2 ± 1.80
WA	0.99 ± 0.11	5.35 ± 1.03	4.80 ± 3.62	3.06 ± 2.17	13.1 ± 9.16
Mean	1.04	4.78	8.95	9.30	18.4
WHO/FAO (2007)	0.8	100	100	300	50

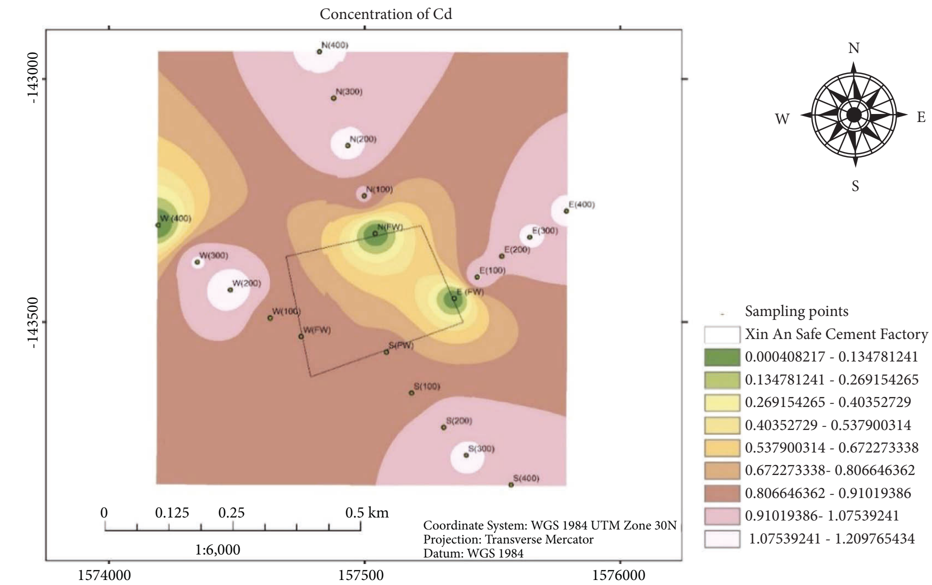
NA = north axis; EA = east axis; SA = south axis; WA =west axis.

observed in this study [36]. Cd, Pb, Cu, Cr, and Zn concentrations in the cement produced from the cement production plant were 6.6, 23.4, 19.1, 10.3, and 56.3 mg/kg which were below the WHO guidelines for Cd (0.8 mg/kg), Pb (50 mg/kg), Cu (100 mg/kg), Cr (100 mg/kg), and Zn (300 mg/kg), respectively [37]. Limestone, shells, and chalk are heated along with shale, clay, slate, blast furnace slag, silica sand, and iron ore in the production of cement. The result is a powder made up primarily of calcium, silica, aluminum, iron, magnesium, and other trace elements such as cadmium, zinc, and copper [38]. Therefore, the relatively high concentrations of heavy metals in the cement could be attributed to the raw material used in cement production [39]. Even if the heavy metal concentrations in the cement were below the allowed level, the continual and sustained deposition in the environment that would result in their buildup might be extremely hazardous to the ecosystem.

3.4. Heavy Metal Concentration in Soil at Various Sampling Sites. Table 4 shows the distribution of heavy metal concentrations in the soil at different geographical locations at the cement production plant. The WHO guidelines were used as a basis of comparison for the heavy metal concentrations detected in cement.

Cd levels in the soil samples ranged from 0.99 to 1.07 mg/kg, with an average of 1.04 mg/kg. The average mean of cadmium was above the FAO/WHO (2007) stipulated limit of 0.8 mg/kg. This high Cd content can be attributed to the oolitic limestone, the raw material used in cement production. This has been reported to contain high levels of heavy metals due to geological reasons [39, 40]. Similarly, Al-Oud et al. [41] reported significant enrichment of Cd in the soils around a cement factory in Saudi Arabia and ascribed it to the metals which are released along the production line of cement making. The eventual deposition of high metal concentration in agricultural soils poses increased hazards of dangerous migration into underground water and eventual transfer up the food chain through plant uptake [42].

Cr is one of the known environmental toxic pollutants in the world [43]. The measured concentration of Cr in the soil ranged from 3.87 to 5.35 mg/kg with a mean of 4.78, which is lower than the FAO/WHO (2007) allowable limit of 100 mg/kg. The low concentration of Cr can be associated with the kiln stage retaining most heavy metals during the production process [44]. Comparatively, Krishna and Govil [45] recorded extremely high levels of Cr (240 mg/kg) in the soil around the Pali Industrial area, Rajasthan, India. Furthermore, 190 mg/kg of Cr has been recorded around the Diamond Cement (Ghana) Limited factory in the Volta Region of Ghana by Addo et al. [36]. Increased amounts of Cr in the environment, on the other hand, can disrupt the chemical and biological processes of the soil, halting plant growth [46].



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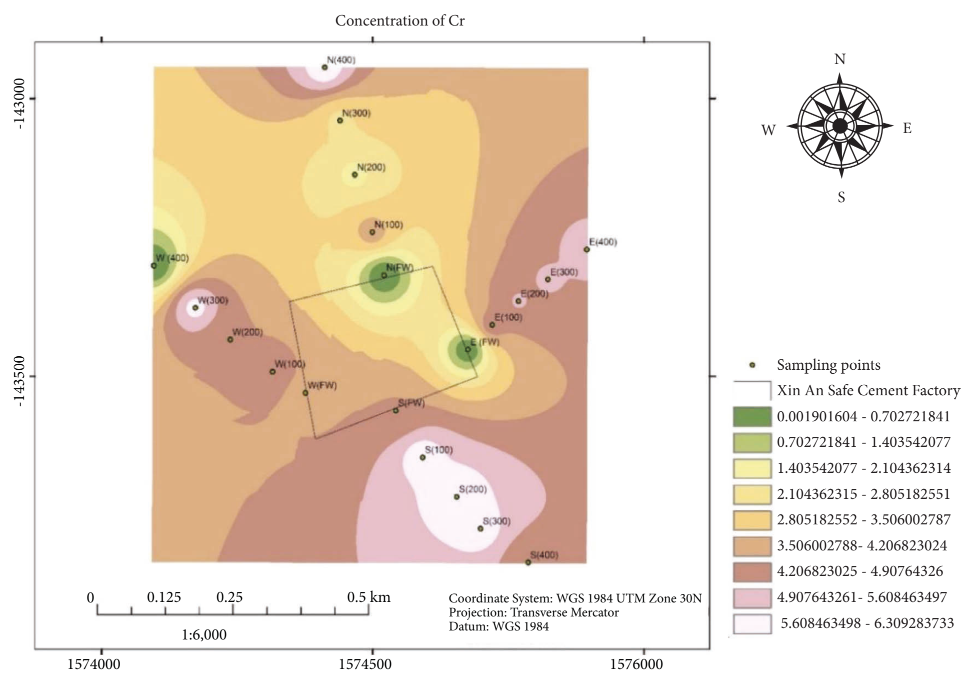
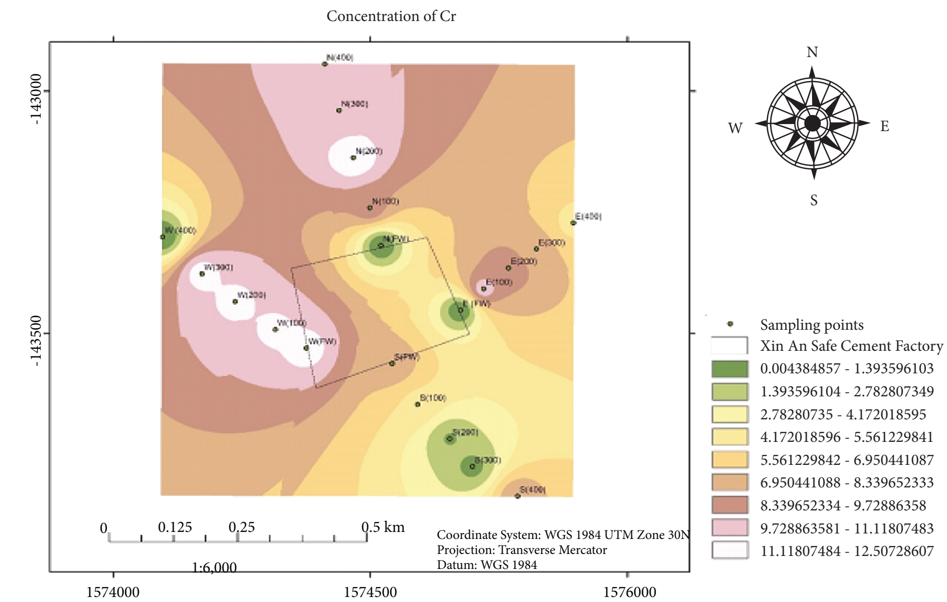


(b)

Figure 5: Continued.



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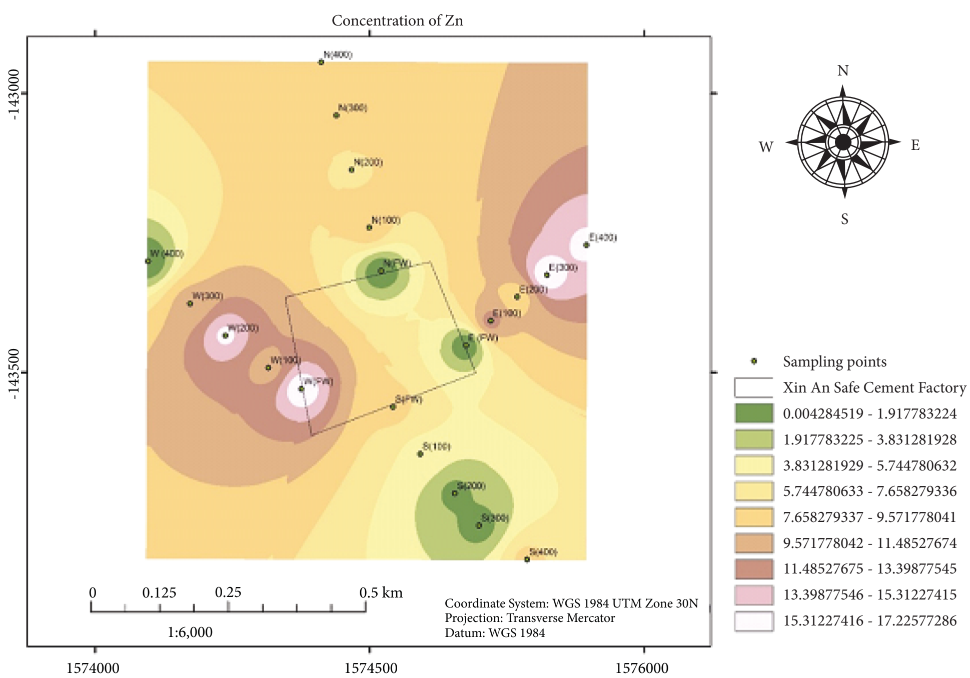

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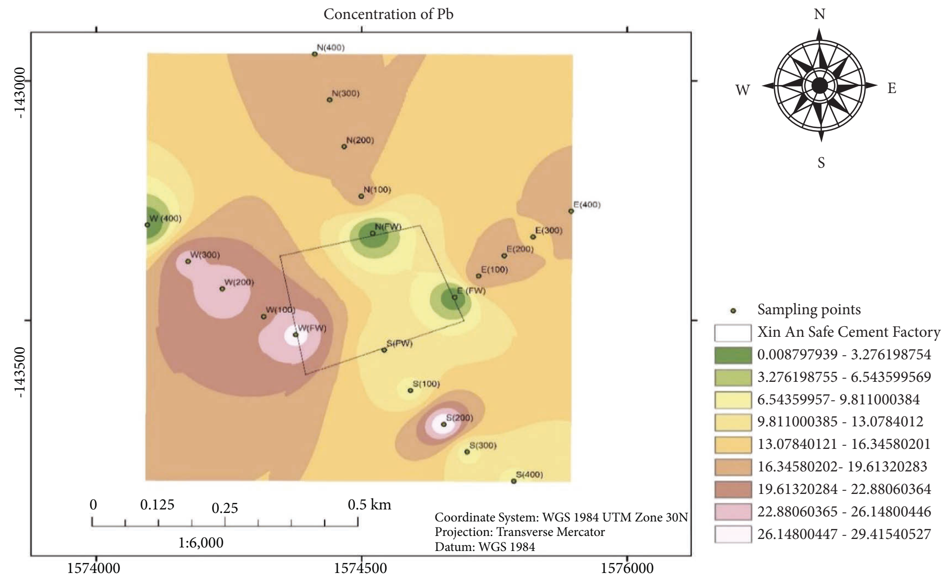

(e)

Figure 5: Spatial distribution of heavy metals in the soil around the cement production plant.

Cu is an essential micronutrient to nearly all higher plants and animals. Al-Khashman and Shawabkeh [40] reported that heavy metals in agricultural soils are mostly sourced through fertilizers, pesticides, wastewater, and diffuse pollution sources like the cement industry. The mean concentrations of Cu ranged from 8.36 to 12.0 mg/kg with a mean of 8.95 mg/kg, which was below the FAO/WHO (2007) stipulated limit of 100 mg/kg for soils. The relatively low concentrations obtained from our study can be attributed to the age of the plant, which is in its sixth year of operation, and hence the low accumulation of heavy metals in the study. Comparatively, similarly low concentrations (12.47 mg/kg) have been reported by Adimalla and Wang (2018) in urban soils of northern Telangana in India. These low values were a result of contributions from the cement factory and agricultural practices.

Zn is an important catalytic element in enzyme processes; however, its concentration varies depending on the type of soil [47]. The Zn concentration of the soils we studied ranged from 3.06 to 12.9 mg/kg. The measured mean value of 9.30 mg/kg is less than the FAO/WHO allowable limit of 300 mg/kg. Research in reference [40] also recorded low levels (44.51 mg/kg) of Zn in their study area in Jordan. However, a higher concentration of Zn (237.96 mg/kg) has been reported in reference [48] around the Shahrood Cement Plant in Iran which was above the stipulated limits.

Pb is a contaminant found in practically every aspect of environmental and biological systems [49]. Lead levels in this study ranged from 13.09 to 25.1 6 mg/kg, with an average of 18.4 mg/kg, much below the FAO/WHO maximum allowed limit of 50 mg/kg. The soil samples with the highest lead levels were found near the cement plant. This may be due to the cement industry's output and the plant's high traffic volume. The low Pb concentrations could be due to the lack of heavy metals in the raw materials utilized in the cement manufacturing process [50]. Excess Pb levels in the soil cause poisoning symptoms in plants, including seed germination inhibition, plant height reduction, reduced tillering, reduced root growth, reduced shoot growth, lower fruit and grain output, and mortality [21].

3.5. Spatial Distribution of Heavy Metals. Using a geographic information system, the spatial distribution of contaminating particle concentrations in the soil was displayed, and the specific surface harmed by the dust deposit was identified. Furthermore, for efficient and long-term soil preservation, geographic knowledge about soil parameters is required [51]. Within the production environment, Figure 5 shows the regional distribution of heavy metals in soil.

The spatial interpolation indicates high visibility and even distribution of Cd around the geographical axes (north, south, east, and west). This is an indication of the high Cd contents found in the production process of cement. This does not come as a surprise since Cd recorded concentrations above the WHO guidelines (Table 4). Cr and Cu recorded metal concentrations below the WHO guidelines, and the spatial distribution of Cr and Cu showed less visibility especially on the northerly axis for Cr and the southerly axis for Cu. This implies that these positions received little to no heavy metal impact from the cement plant. The study showed hotspots of Pb at the west and south axes whiles Zn was highly concentrated in the southern and western areas of the cement plant. Zinc and lead showed a contrast distribution pattern from those observed with Cd, Cr, and Cu. This indicates that although air deposition of contaminated dust is a potential source of metals, the source of pollution of Zn and Pb near the cement mill cannot be limited to releases from cement manufacturing. The study showed scattered hotspots of Zn and Pb, which implicates other sources as potential sources

Table 5: Pearson correlation coefficient matrix of heavy metal in soil samples.

	Cd	Cr	Cu	Zn	Pb
Cd	1.000				
Cr	−0.659	1.000			
Cu	0.989*	−0.558	1.000		
Zn	0.788	−0.230	0.868	1.000	
Pb	0.851	−0.175	0.896	0.816	1.000

* = correlation is significant at the 0.05 level (2-tailed).

Table 6: Principal component analysis of heavy metals in soil samples.

Parameter	Factor 1	Factor 2
Pb	**0.966**	—
Zn	**0.930**	**0.995**
Cu	**0.892**	0.452
Cd	**0.820**	0.565
Cr	—	−0.991
% variance	68.783	30.211
% cumulative	68.783	95.995

Bold loadings are statistically significant.

of contamination, especially vehicular transportation and agricultural activities.

3.6. Correlation and Principal Component Analysis (PCA). The degree of correlation between the logarithms of the metal data was examined using Pearson's correlation coefficient matrix. Table 5 displays Pearson's correlation coefficient matrix values for heavy metals in soil samples.

The results show a strong positive significant linear correlation between the metals Pb vs. Cd, Pb vs. Cu, and Pd vs. Zn ($r = 0.851$, 0.896, and 0.816, respectively). This confirms the probable common origin of the studied metals except for Cr which recorded a weak negative correlation with Pb ($r = -0.175$). Zn had a strong positive significant correlation with Cd and Cu ($r = 0.788$ and 0.868, respectively) and a weak negative linear correlation between Zn and Cr ($r = -0.230$). There was a very strong positive significant linear correlation between Cu and Cd ($r = 0.989$) and a weak negative relationship between Cu and Cr ($r = -0.558$). Cr and Cd recorded a strong-weak negative linear correlation of $r = -0.659$. The strong relationship between Cd and Cu could also be due to bedrock contribution.

After varimax rotation, the PCA was performed using factor extraction with an eigenvalue greater than one (>1). The varimax approach was used, which involves rotating the primary component. Table 6 shows the relevant factor loadings obtained by PCA with varimax for numerous heavy metals. In the table, loadings with a 0.70 (to see strongly associated parameters) or higher mark are bolded.

Table 6 indicates that factor 1 (major contributors) accounts for 68.8% of the total variance while at the same time having high loadings on the chemical constituents Pb, Zn, Cu, and Cd. This implies that effluents from the cement production plant are major contributors to soil contamination in the study area. On the other hand, factor 2 (minor contributors) also posits that about 30% of the total variance is made up of Zn. This indicates that the soil studied had high loadings of anthropogenic and lithogenic sources. The results obtained from the statistical analysis indicate that cement emissions represent the most significant heavy metal source contamination in the area under investigation.

4. Conclusion

The study presents the rate of dust deposition relative to the distance at the various geographical axes of the cement production plant and its consequent heavy metal contamination of the soil around the cement factory. The findings indicate that there is significant emission of cement dust into the environment around the cement factory. Emissions were observed up to a maximum of 200 m distance from the cement facility. However, the highest rate of deposition was observed at the southern axis of the factory with an average value of 60.20 mg/m^2/day and the lowest at the northern axis with an average value of 39.26 mg/m^2/day. The high loading rates at the southwesterly could be associated with wind direction. Heavy metals were found in large amounts in the soil samples near the cement facility, particularly along the southern axis. The investigation revealed extreme contamination by Cd, exceeding the WHO/FAO permissible limit, which poses some level of environmental concern in the vicinity of the cement plant. From the spatial mapping, it showed an even distribution of Cd with some hotspots close to the factory whiles for the other metals the hot spots were observed far away from the factory. According to the PCA results, factor 1 accounted for 68.8% of the total variance while at the same time having high loadings on the chemical constituents Pb, Zn, Cu, and Cd while factor 2 also suggests that about 30% of the total variance was made up of Zn. This suggests that both anthropogenic and lithogenic factors represent the major sources of soil contamination in the factory area. There was a strong significant linear correlation between As and Ni while Cr vs. As and Ni indicated a weak linear correlation and a strong negative insignificant linear correlation between metals such as Pb vs. As and Ni. There was a weak negative relationship between metals such as Cr vs. Pb, Cu, Cd, and Zn. Heavy metals such as Cd, Cu, Zn, and Pb all had a strong positive linear relationship. The management of the cement factory must put in place appropriate measures such as dust emission control to minimize dust emissions in the vicinity of the cement plant.

Data Availability

Data will be made available upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

[1] S. Mishra and N. A. Siddiqui, "A review on environmental and health impacts of cement manufacturing emissions,"

International Journal of Geology, agriculture and environmental sciences, vol. 2, no. 3, pp. 26–31, 2014.
[2] O. O. Olasumbo, A. O. Hakeem, O. O. Juwon, and A.-T. O. Francisca, "Environmental and health impact of cement factory production in Ibese, Ogun State, Nigeria," *Applied Environmental Research*, vol. 38, no. 2, pp. 93–110, 2016.
[3] D. S. Thambavani and R. S. Kumar, "Effect of cement dust on photosynthetic pigments of selected plant species," *Asian Journal of Environmental Science*, vol. 6, no. 2, pp. 161–167, 2011.
[4] M. Murugesan, A. Sivakumar, N. Jayanthi, and K. Manonmani, "Effect of cement dust pollution on physiological and biochemical activities of certain plants," *Pollution Research*, vol. 23, no. 2, pp. 375–378, 2004.
[5] S. Bilen, "Effect of cement dust pollution on microbial properties and enzyme activities in cultivated and no-till soils," *African Journal of Microbiology Research*, vol. 4, no. 22, pp. 2418–2425, 2010.
[6] Z. K. Zeleke, B. E. Moen, and M. Bråtveit, "Cement dust exposure and acute lung function: a cross shift study," *BMC Pulmonary Medicine*, vol. 10, no. 1, pp. 19–28, 2010.
[7] S. K. Shukla, N. A. Singh, V. Kumar et al., "Impact of dust emission on plant vegetation in the vicinity of cement plant," *Environmental Engineering and Management Journal*, vol. 7, no. 1, pp. 31–35, 2008.
[8] D. K. Gupta and L. M. Sandalio, *Metal Toxicity in Plants: Perception, Signaling and Remediation*, Springer Science and Business Media, Berlin, Germany, 2011.
[9] P. Opoku, E. Gikunoo, E. K. Arthur, and G. Foli, "Removal of selected heavy metals and metalloids from an artisanal gold mining site in Ghana using indigenous plant species," *Cogent Environmental Science*, vol. 6, no. 1, Article ID 1840863, 2020.
[10] V. Pereira, M. Miranda, J. Sierra, J. L. Benedito, and M. López-Alonso, "Toxic and essential trace element concentrations in different tissues of extensively reared sheep in northern Spain," *Journal of Food Composition and Analysis*, vol. 96, Article ID 103709, 2021.
[11] K. Zhao, W. Fu, Q. Qiu et al., "Spatial patterns of potentially hazardous metals in paddy soils in a typical electrical waste dismantling area and their pollution characteristics," *Geoderma*, vol. 337, pp. 453–462, 2019.
[12] J. H. Potgieter, "An Overview of Cement production: ho"green" and sustainable is the industry?" *Environmental Management and Sustainable Development*, vol. 1, no. 2, p. 14, 2012.
[13] J. G. Tapali, S. Demis, and V. G. Papadakis, "Sustainable concrete mix design for a target strength and service life," *Computers and Concrete*, vol. 12, no. 6, pp. 755–774, 2013.
[14] G. Asiamah, "Heavy metal concentration in the Owere river at Konongo," *M.Sc. Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana*, 2013.
[15] G. S. Service, *Population & Housing Census Report: Urbanisation in Ghana*, Ghana Statistical Service, Accra, Ghana, 2010.
[16] J. A. Yeboah, *Assessment of Infant Feeding and Care Practices Among Nursing Mothers in Asante Akim Central*, University of Education, Winneba, Ghana, 2016.
[17] S. Dominy and B. Van Lente, *Annual Qualified Persons Report for the Obenemase A and B Lodes, Konongo Gold Project, Ghana-Year Ended 31 March 2014*, LionGold Corporation Limited, Singapore Exchange Securities Trading Limited Practice, 2014.
[18] P. M. Nude, G. Foli, and S. M. Yidana, "Geochemical assessment of impact of mine spoils on the quality of stream sediments within the Obuasi mines environment, Ghana," *International Journal of Geosciences*, vol. 02, no. 03, pp. 259–266, 2011.
[19] C. Z. Li, Y. Zhao, and X. Xu, "Investigation of dust exposure and control practices in the construction industry: implications for cleaner production," *Journal of Cleaner Production*, vol. 227, pp. 810–824, 2019.
[20] J. Dierig, "Choosing a woven wire screen for top separation performance," *Technical Report, Powder and bulk engineering*, vol. 15, 2006.
[21] D. S. Baah, E. Gikunoo, G. Foli, E. K. Arthur, and P. Entsie, "Health risk assessment of trace metals in selected food crops at Abuakwa South Municipal, Ghana," *Environmental Monitoring and Assessment*, vol. 193, no. 9, pp. 609–613, 2021.
[22] G. Foli, S. K. Gawu, J. Manu, and P. M. Nude, "Arsenic sorption characteristics in decommissioned tailings dam environment at the Obuasi Mine, Ghana," *Research Journal of Environmental and Earth Sciences*, vol. 5, no. 10, pp. 599–610, 2013.
[23] S. Fan, X. Wang, J. Lei, Q. Ran, Y. Ren, and J. Zhou, "Spatial distribution and source identification of heavy metals in a typical Pb/Zn smelter in an arid area of northwest China," *Human and Ecological Risk Assessment: An International Journal*, vol. 25, no. 7, pp. 1661–1687, 2019.
[24] D. F. Watson and G. Philip, "A refinement of inverse distance weighted interpolation," *Geo-Processing*, vol. 2, no. 4, pp. 315–327, 1985.
[25] C. Mattei, H. Wortham, and E. Quivet, "Heterogeneous atmospheric degradation of pesticides by ozone: influence of relative humidity and particle type," *Science of the Total Environment*, vol. 625, pp. 1544–1553, 2018.
[26] C. M. Carrico, P. Kus, M. J. Rood, P. K. Quinn, and T. S. Bates, "Mixtures of pollution, dust, sea salt, and volcanic aerosol during ACE-Asia: radiative properties as a function of relative humidity," *Journal of Geophysical Research*, vol. 108, no. D23, p. 8650, 2003.
[27] K. C. Dannemiller, C. J. Weschler, and J. Peccia, "Fungal and bacterial growth in floor dust at elevated relative humidity levels," *Indoor Air*, vol. 27, no. 2, pp. 354–363, 2017.
[28] S. Howell, A. Clarke, Y. Shinozuka et al., "Influence of relative humidity upon pollution and dust during ACE-Asia: size distributions and implications for optical properties," *Journal of Geophysical Research: Atmospheres*, vol. 111, 2006.
[29] Y. Tunckaya, "Performance analysis of novel air pollution forecasting system design in a Turkish cement plant via neural and neuro-fuzzy soft computing," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, vol. 40, pp. 1–16, 2020.
[30] S. Roy, G. Adhikari, T. Renaldy, and T. Singh, "Assessment of atmospheric and meteorological parameters for control of blasting dust at an Indian large surface coal mine," *Research Journal of Environmental and Earth Sciences*, vol. 3, no. 3, pp. 234–248, 2011.
[31] J. G. Watson, S. L. Altshuler, and J. C. Chow, "Oil sands research bibliography," *Journal of the Air and Waste Management Association*, vol. 69, no. 10, pp. S1–S36, 2019.
[32] T. Aljazzar and B. Kocher, "Monitoring of contaminant input into roadside soil from road runoff and airborne deposition," *Transportation Research Procedia*, vol. 14, pp. 2714–2723, 2016.

[33] T. L. Thatcher and D. W. Layton, "Deposition, resuspension, and penetration of particles within a residence," *Atmospheric Environment*, vol. 29, no. 13, pp. 1487–1497, 1995.

[34] A. Gbadebo and O. Bankole, "Analysis of potentially toxic metals in airborne cement dust around Sagamu, Southwestern Nigeria," *Journal of Applied Sciences*, vol. 7, no. 1, pp. 35–40, 2006.

[35] E. Adeyanju and C. A. Okeke, "Exposure effect to cement dust pollution: a mini review," *SN Applied Sciences*, vol. 1, no. 12, pp. 1572–1617, 2019.

[36] M. A. Addo, E. O. Darko, C. Gordon et al., "Evaluation of heavy metals contamination of soil and vegetation in the vicinity of a cement factory in the Volta Region, Ghana," 2012.

[37] Who, *Air Quality Guidelines for Europe*, WHO, Copenhagen, Denmark, 1997.

[38] N. Makul, *Principles of Cement and Concrete Composites*, Springer Nature, Berlin, Germany, 2021.

[39] J. A. Oates, *Lime and Limestone: Chemistry and Technology, Production and Uses*, John Wiley and Sons, New York, NJ, USA, 2008.

[40] O. A. Al-Khashman and R. A. Shawabkeh, "Metals distribution in soils around the cement factory in southern Jordan," *Environmental Pollution*, vol. 140, no. 3, pp. 387–394, 2006.

[41] S. Al-Oud, M. Nadeem, and B. Al-Shbel, "Distribution of heavy metals in soils and plants around a cement factory in Riyadh city, central of Saudi Arabia," *American-Eurasian Journal of Agricultural and Environmental Sciences*, vol. 11, no. 2, pp. 183–191, 2011.

[42] A. Mocek, W. Spychalski, A. Dobek, and A. Mocek-Płóciniak, "Comparison of three methods of copper speciation in chemically contaminated soils," *Polish Journal of Environmental Studies*, vol. 21, no. 1, p. 159, 2012.

[43] N. K. A. Jabbari, M. F. Ghasemi, A. Khosravan, A. Farahmand, and M. R. Shakibaie, *Cadmium bioremediation by metal-resistant mutated bacteria isolated from active sludge of industrial effluent*, pp. 279–286, 2010.

[44] J. Zhang, J. Liu, C. Li, Y. Jin, Y. Nie, and J. Li, "Comparison of the fixation effects of heavy metals by cement rotary kiln co-processing and cement based solidification/stabilization," *Journal of Hazardous Materials*, vol. 165, no. 1–3, pp. 1179–1185, 2009.

[45] A. K. Krishna and P. K. Govil, "Heavy metal contamination of soil around Pali industrial area, Rajasthan, India," *Environmental Geology*, vol. 47, no. 1, pp. 38–44, 2004.

[46] P. C. Nagajyoti, K. D. Lee, and T. V. M. Sreekanth, "Heavy metals, occurrence and toxicity for plants: a review," *Environmental Chemistry Letters*, vol. 8, no. 3, pp. 199–216, 2010.

[47] M. Knezevic, D. Stankovic, B. Krstic, M. S. Nikolic, and D. Vilotic, "Concentrations of heavy metals in soil and leaves of plant species Paulownia elongata S. Y. Hu and Paulownia fortunei Hemsl," *African Journal of Biotechnology*, vol. 8, no. 20, 2009.

[48] F. Sereshki and A. Saffari, "Environmental impact assessment and sustainability level determination in cement plants (Case study: shahrood cement plant)," *Iranian Journal of Earth Sciences*, vol. 8, no. 2, pp. 90–101, 2016.

[49] Y. Lei, Q. Zhang, C. Nielsen, and K. He, "An inventory of primary air pollutants and CO_2 emissions from cement production in China," *Atmospheric Environment*, vol. 45, no. 1, pp. 147–154, 2011.

[50] Y. Arfala, J. Douch, A. Assabbane, K. Kaaouachi, H. Tian, and M. Hamdani, "Assessment of heavy metals released into the air from the cement kilns co-burning waste: case of Oujda cement manufacturing (Northeast Morocco)," *Sustainable Environment Research*, vol. 28, no. 6, pp. 363–373, 2018.

[51] Y. Deng, L. Jiang, L. Xu et al., "Spatial distribution and risk assessment of heavy metals in contaminated paddy fields–A case study in Xiangtan City, southern China," *Ecotoxicology and Environmental Safety*, vol. 171, pp. 281–289, 2019.