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Original Research Article

Assessment of Potentially Toxic Element Accumulation and Pollution Indices in Soils Surrounding a Cement Manufacturing Facility in Obajana, Nigeria

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Abstract

Cement production can release dust and mineral elements into the surrounding environment, potentially affecting the quality of nearby soils. This study assessed the concentrations and contamination levels of Zn, Ca, Ba, Ni and Ti in soils around a cement manufacturing facility in Obajana, Kogi State, Nigeria. Soil samples were collected from four locations around the facility and analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES). The concentrations of Zn, Ca, Ba, Ni and Ti ranged from 194.33–286.28, 22,526.41–25,043.99, 114.16–159.30, 24.43–27.31 and 287.76–330.73 mg/kg, respectively. The concentrations of Zn, Ba, and Ni were below their respective guideline values, however, specific guideline values were not available for Ca and Ti. The extent of contamination was further assessed using enrichment factor (EF), contamination factor (CF), pollution load index (PLI) and geo-accumulation index (Igeo). Nickel showed no enrichment, Zn was in the range of minor to moderate enrichment while Ba and Ca showed low enrichment, suggesting contributions from both natural and human activities. The CF values indicated low to considerable contamination, and the PLI values (1.88–2.88) showed that the soils were affected by varying degrees of contamination. The Igeo values indicated moderate contamination by Zn and Ca. Overall, the findings suggest that activities associated with the cement manufacturing facility may be contributing to the enrichment of some elements in the surrounding soils. Regular monitoring of soil quality is therefore recommended to assess changes in elemental concentrations over time.

Introduction

Soil acts as the main repository for potentially toxic elements deposited through various medium (Abdulsalam et al., 2026). The contamination of soil by potentially toxic elements caused by manmade activities has been a serious environmental issue as a result of their toxicity, and resistance to natural decomposition, and effects on human health (Upahi et al., 2025; Yahaya et al., 2025). Potentially toxic elements may occur naturally in the environment through geogenic processes such as weathering of parent materials (Kolo et al., 2018; Abdulsalam et al 2024).

The cement industry plays an important role in infrastructure development and economic growth. However, cement production is also associated with the release of dust and elements into the surrounding environment. Activities such as handling of raw materials, clinker production, grinding and transportation of cement can generate dust that is deposited on nearby soil, vegetation and water bodies (Yahaya et al., 2024; Abdulsalam et al., 2025). Continuous deposition of cement dust may change the mineral composition and some physicochemical properties of the surrounding soil (Zerrouqi et al., 2008). People living close to a cement manufacturing plant may therefore be exposed to these elements through direct contact with contaminated soil and plants through the food chain (Abdulsalam et al., 2025).

Previous studies have reported metal contamination around cement manufacturing facilities in Nigeria. Abdulsalam et al. (2026) reported moderate to high contamination factors for metals in soils around a cement plant in North-Central Nigeria. Furthermore, Yahaya et al. (2024) reported hazard quotient, hazard index, and cancer risk values of metals in soils around a cement facility in Sokoto, Nigeria, with some metals exceeding recommended limits.

Obajana, Kogi State, is one of the major cement-producing areas in Nigeria. Although cement production has contributed significantly to economic activities in the area, there is limited information on the current contamination status of soils around the cement manufacturing facility.

Therefore, this study assessed the concentrations and contamination levels of selected elements (Zn, Ca, Ba, Ni and Ti) in soils around the Obajana cement manufacturing facility, Kogi State, Nigeria. Zinc, Barium, and nickel were considered in relation to their potential environmental importance, while calcium and titanium were included as major and mineral-associated elements that may reflect cement-related inputs and changes in soil elemental composition. The contamination indices were used to assess the degree of elemental enrichment and accumulation relative to background conditions rather than to imply equivalent toxicological effects for all investigated elements. In this study, the concentrations measured at the control site were used as the background values for calculating the contamination indices.

The degree of contamination was evaluated using enrichment factor, contamination factor, pollution load index and geo-accumulation index.

Materials and Methods

Study area

Samples of soil were obtained from sampling sites (A, B, C, and D) in the Obajana area. Ten composite soil samples were collected from each sampling site, giving a total of 40 composite soil samples. At each site, soil samples were collected from designated sampling points within the site, thoroughly homogenized, and treated as composite samples for subsequent laboratory analysis. The geographical coordinates of the four sampling sites were recorded using a GPS (Garmin Montana 700) device. The sites were located within latitude 7.91255(°N)-7.90768(°N) and longitude 6.43797(°E) – 6.44415(°E) (Figure1). Obajana is a small town that lies within the Lokoja Local Government Area of Kogi State, Nigeria. It gained popularity following the Dangote Cement Factory that was established there, which is ranked as the leading cement manufacturing plant in Africa (Owoleke et al., 2023). Obajana is characterized by an average highest temperature of 33^{o}C and an average lowest temperature of 22.80 °C, with generally hot weather throughout the year. The area is identified with its wet and dry periods (Owoleke et al., 2023). The dominant rock types in the area are pegmatite, limestone, granulite, schist, quartzite, and granite (Afeni et al., 2008). The soil is predominantly sandy loam with a mean pH of 5.80. These soils are naturally fertile and support crop yield without the aid of fertilizer (Charles et al., 2022).

Sample collection

Soil samples were obtained at depth of 0-15 cm using a clean shovel. A soil control sample was also obtained. The dried soil samples were meticulously mixed in a clean plastic bucket to obtain a representative sample, crushed and sieved through a < 2 mm mesh, and preserved in branded polythene bags before analysis (Sabir et al., 2022).

Soil sample digestion

A sample (1g) was added to a 28 mL mixture of HNO_3 and HCl in the ratio of 1:3 (Sigma-Aldrich) in a 250 mL beaker. The beaker was slowly stimulated to make sure the reactants mixed properly, then agitated on a heating mantle for 5 hours at 120°C. The beaker was left to cool, 2ml portion of Hydrogen peroxide was added later to the suspension and further agitated for 10 minutes. Whatman No. 42 filter paper (Sigma-Aldrich) was used to filter the resulting solution, followed by washing with 3% HNO_3 acid into a 50 mL volumetric flask. Chemical analyses were carried out with an Agilent Technologies 720 ICP-OES (Shaheen et al., 2022). The aqua regia procedure provides a pseudo-total extraction and may not completely dissolve elements associated with resistant silicate mineral phases. This limitation is particular to Ti, therefore the Ti concentrations obtained represents the aqua-regia exchangeable fraction rather than the total Ti concentration in the soil.

Quality assurance and Quality Controls

All analyses were performed in triplicate, with reagent blanks included to assess potential contamination and verify reagent purity. Analytical grade chemicals and reagents procured from Sigma-Aldrich, Germany were used throughout the analytical procedures. All glassware was thoroughly washed with teepol, rinsed with HNO_3 solution and subsequently washed with deionized water. Calibration curves were created using standard solutions of target metals. The analytical method was authenticated by assessing linearity, precision, and accuracy. The quality and reliability of the analytical results were assessed through recovery studies using matrix spikes for each element. The recovery tests were conducted by adding known concentrations of standard solutions to the sample matrices before to digestion. The average recoveries ranged from 98.45 ± 0.65 to 101.05± 2.03%, indicating satisfactory analyte recovery under the analytical conditions employed. No certified reference material (CRM) was analysed in this study, therefore analytical accuracy could not be independently verified against certified reference value. The matrix –spike recovery results provide evidence of satisfactory analyte recovery but do not constitute an independent CRM based assessment of accuracy.

Assessment of soil pollution

Enrichment factor (EF)

The EF of elements is a tool used to determine the presence and amount of contaminants due to human activities (Akoto and Anning, 2021). It was evaluated using the formula below:

$EF = Ci/Crf\ (sample)\ /Bi/Brf\ (background)$ (Akoto and Anning, 2021). (1)

Ci represents the level of metal in the soil sample; Crf stands for the level of the reference element in the soil sample; Bi is the content of the background study metal, and Brf is the concentration of the reference element in the background. Enrichment factors of the investigated elements were determined using Ti as the reference metal because of its high stability and predominantly natural, geogenic origin with minimal contribution from anthropogenic sources. However, because the aqua regia digestion may not completely dissolve Ti bearing silicate minerals, the resulting Ti concentrations may represent a partial rather than total extractable Ti fraction. Therefore, the Ti –normalized EF values were interpreted cautiously as relative enrichment indicator definite measure of anthropogenic contribution. EF values were classified as follows: EF < 1 indicating no enrichment, 1 < EF < 3 indicating minor enrichment, 3 < EF < 5 revealing moderate enrichment, 5 < EF < 25 suggesting severe enrichment, 25 < EF < 50 indicating very severe enrichment, and EF > 50 suggesting extremely severe enrichment (Sabir et al., 2022; Abdullateef et al., 2024).

Contamination factor (CF)

The CF is used to evaluate the extent of metal contamination in soil by relating the concentration of metal of the interest in the sample with its concentration in the background. A CF assessment below 1 shows low contamination; values from 1 to 3 indicate moderate contamination; values in the range of 3 to 6 indicate considerable contamination; while values above 6 indicate very high contamination (Sabir et al., 2022; Abdullateef et al., 2024).

CF = Concentration of heavy metal in the sample (mg kg^{-1} DW)/ Background concentration of the heavy metal (mg kg^{-1} DW). (2)

Geo-accumulation index (Igeo)

The Igeo is used to evaluate the rate of heavy metal pollution in soil by comparing the calculated levels of the metal with its concentration in the background. Cn represents the calculated concentration of the metal in the sample, while Bn represents the background concentration of the same metal. The constant value of 1.5 was used as a correction factor to account for potential variations in background metal concentrations (Sabir et al., 2022).

$$Igeo = \log_2 (Cn/ 1.5 \times Bn) \quad (3)$$

The Igeo is grouped in the following classes: Igeo ≤ 0 signifies unpolluted; 0 < Igeo ≤ 1 reveals unpolluted to moderately polluted;1 < Igeo ≤ 2 indicates moderately polluted; 2 < Igeo ≤ 3 implies moderately to heavily polluted; 3 < Igeo ≤ 4 signifies heavily polluted; 4 < Igeo ≤ 5indicates heavily to extremely polluted.

Pollution load index (PLI)

The PLI is used for the determination of the total contamination status of a particular location. It also summarizes the estimation of entire soil contamination (Vineethkumar et al., 2020).

The PLI can be computed using the equation below:

$$PLI = [CF_1 \times CF_2 \times CF_3 \times \cdots \times CFn]^{1/n} \quad (4)$$

Where CF is the contamination factor of and n is the number of metals. The PLI values can be categorized as PLI < 1 (No pollution), 1< PLI < 2 (moderate pollution), 2< PLI < 3 (heavy pollution), and PLI >3 (extremely heavy pollution) (Hakanson, 1980).

Statistical Analysis

The results obtained from the investigation were subjected to One-way ANOVA followed by Dunnett's multiple-comparison test between the study soils and the control using the 2024 version of Origin Pro.

Results and Discussion

Results

Concentration of selected elements in soil sample

The concentrations of Zn, Ba, Ca, Ni, and Ti in the soil from the study locations are displayed in Table 1. The mean concentration levels followed the order Ca>Ti>Zn> Ba> Ni. Nickel recorded the least concentration across all sampling sites while Calcium was the most abundant element with concentrations ranging from 22626.41 to 25043.99 (mg kg^{-1}). The concentrations of Ti, Zn, Ba, and Ni ranged from 287.76 to 330.73 (mg kg^{-1}), 194.33 to 286.28(mg kg^{-1}), 114.16 to 159.30 (mg kg^{-1}), and 24.43 to 27.31(mg kg^{-1}) respectively. One-way ANOVA showed significant difference observed for Zn ($F = 16.96$, $p<0.001$), Ca ($F=32.36$, $p< 0.001$), Ti ($F=7.19$, $p\leq 0.05$), Ba ($F=2.40$, $p>0.05$), and Ni ($F=0.19$, $p> 0.05$) from the control values (mg kg^{-1}) Zn 60.23, Ca 6290.39, Ba 75.79, Ti 209.82, and Ni 23.22. The concentrations of Zn, Ba, and Ni were below their guideline value of CCME (2007). Specific guideline values were not available for Ti and Ca. The significantly high concentrations of Zn, Ba, Ca, and Ti in the investigated site compared with the control indicate differences in the elemental composition of the soil around the cement plant.

Soil contamination indices

Enrichment factor (EF)

The EF of the investigated selected elements in the study sites is displayed in Figure 2. Zn showed the highest EF, ranging from 2.27 to 3.28 which falls in the class of minor to moderate enrichment with the highest value recorded at site A (3.28)(moderate enrichment) whereas Ni had the lowest EF value ranging from 0.73- 0.81 which falls in the class of no enrichment with the lowest value occurring at site C (0.73). The EF varied from 2.49-2.74 and 1.14-1.97

for Ca and Ba, respectively which all falls in the class of minor enrichment. The EF order was Zn>Ca>Ba>Ni.

Contamination factor (CF)

The CF of the investigated selected elements is summarized in Figure 3. Zn showed the highest CF ranging from 3.24-4.75 with highest mean recorded at location A (4.75) while Ni had the least CF value varying from 1.05-1.18 with the lowest value occurring at site D (1.05). The CF values for Ca, Ba, and Ti were 3.58-3.98, 1.51-2.10, and 1.37-1.58, respectively. The CF order was Ni<Ti<Ba<Ca<Zn.

Pollution load index (PLI)

The PLI of the analyzed elements is shown in Figure 3. The results revealed that site C recorded the highest PLI with a mean of 2.28, whereas site D recorded the lowest with a mean of 1.88. The PLI order was C>A>B>D.

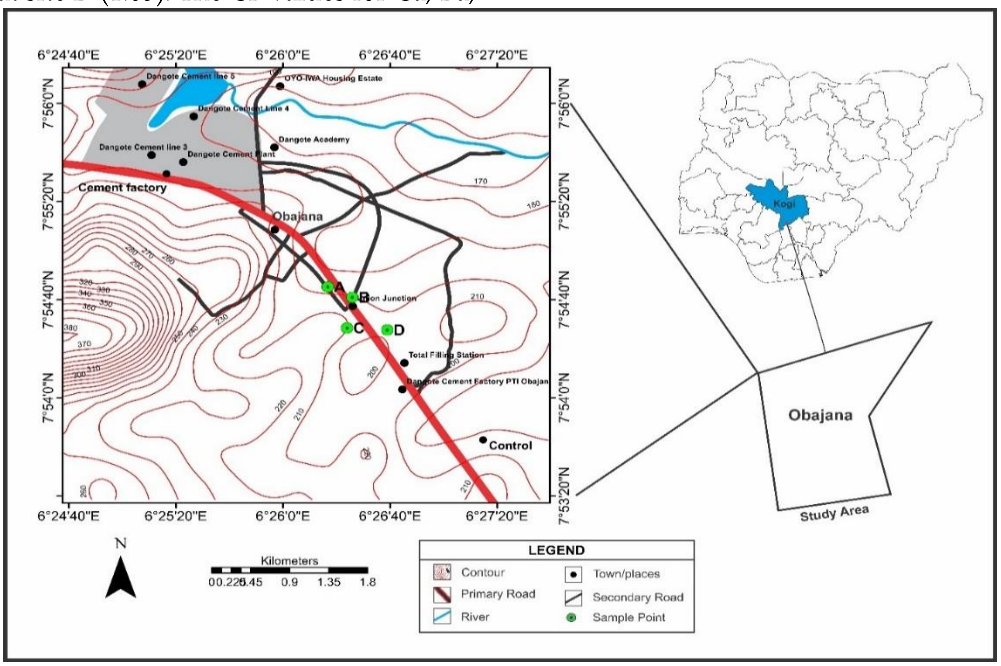

Figure 1: Map showing the sample sites

Source: Author's field work coordinates

Table 1: Concentration of selected elements in soil sample from the study sites (mg/kg)

Site	Zn	Ca	Ba	Ni	Ti
A (n=10)	286.28	25043.99	148.97	27.31	304.45
B (n=10)	239.32	22526.41	122.59	24.44	287.76
C (n=10)	277.87	24698.97	159.30	26.8	330.73
D (n=10)	194.33	23063.73	114.16	24.43	297.88
Mean	249.45	23833.27	136.25	25.75	305.21
STD	42.05	1226.83	21.35	1.53	18.35
MIN	194.33	22526.41	114.16	24.43	287.76
MAX	286.28	25043.99	159.30	27.31	330.73
Control	60.23	6290.39	75.79	23.22	209.82
Limit (CCME, 2007)	360	-	2000	50	-

Note: n=10 composite soil samples per site. The overall Mean, SD, Min, and Max were calculated from the four site (A, B, C, and D) means.

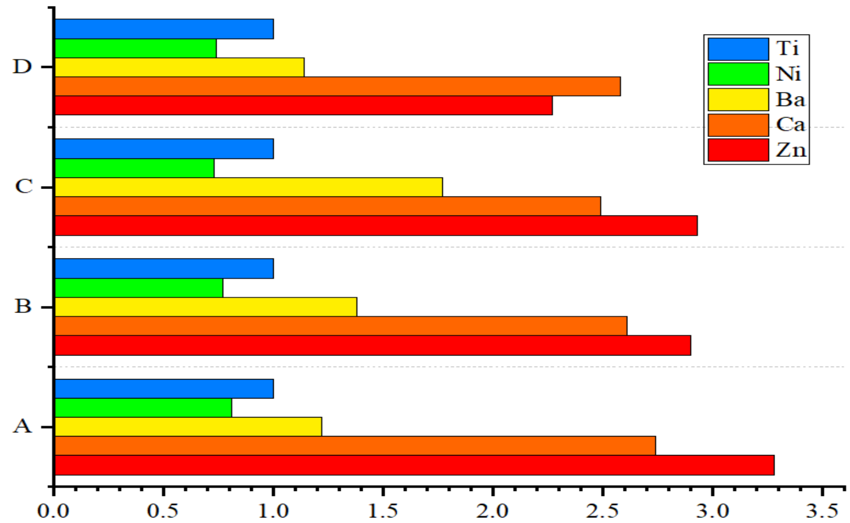

Figure 2: Enrichment factor of selected elements in the soil

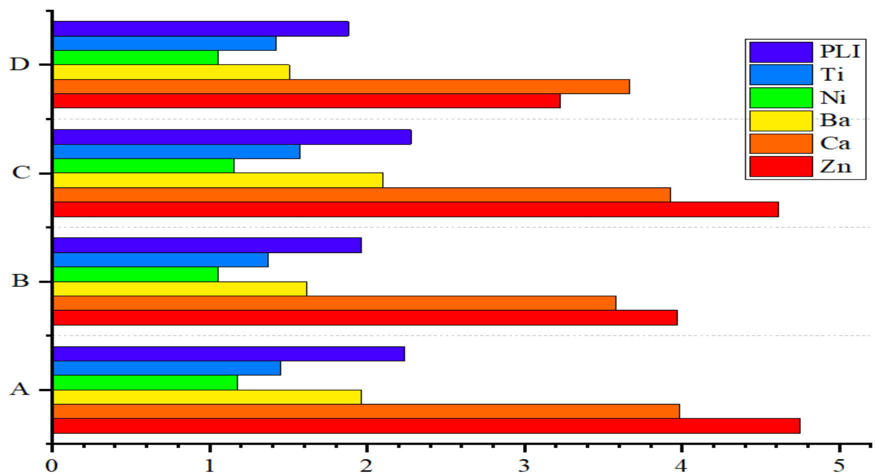

Figure 3: Pollution load index and contamination factor of the selected elements in soil

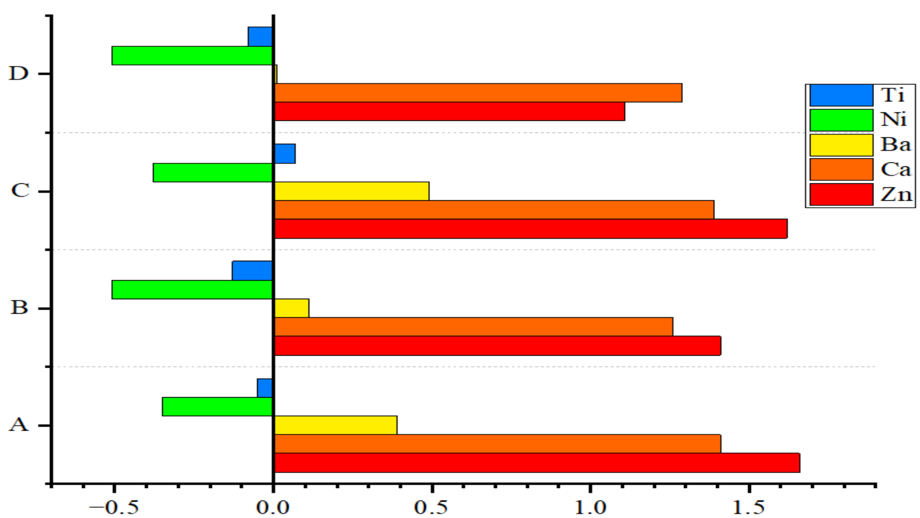

Figure 4: Geo-accumulation index of the selected elements in soil

Geo-accumulation index (Igeo)

The Igeo results of the investigated elements in the study area are presented in Figure 4. Zn recorded the highest Igeo (1.66) at site A, while Ni recorded the lowest Igeo (-0.51) at site B. The Igeo values for Zn, Ca, Ba, Ni, and Ti varied as follows: 1.11to1.66, 1.26 to1.41, 0.01 to 0.49, -0.51to -0.35, and -0.13 to 0.07, respectively. Generally, the Igeo order was Zn > Ca> Ba> Ti>Ni

Discussion

Concentration of selected elements in soil sample

Elevated concentrations of calcium in the study sites may be attributed to its calcareous nature, its calcium rich raw materials used in cement production particularly limestone, as well as deposition of cement dust around the plant (Adebiyi et al., 2021; Khan et al., 2025).

The Ca concentration recorded in this study is higher than that reported by Adebiyi et al. (2021) in forest topsoil near a cement factory in North Central, Nigeria, and by Khan et al. (2025) for a cement factory in western Iraq. Differences in raw materials, local geology, production processes, and distances of the study sites from the emission source may partly account for the variation between studies. The movement of heavy duty trucks and resuspension of deposited cement dust may also contribute to the redistribution of Ca- rich particles within the study area. Continuous deposition of Ca-rich cement dust particle may influence soil properties, particularly soil pH, and favors the formation of calcium carbonate under suitable conditions. These changes can affect availability and may also influence the mobility and bioavailability of other elements in the soil. Therefore, the elevated Ca observed in the study area suggest cement related mineral inputs and possible changes in soil chemistry rather than as direct toxicity concern.

The concentration of Zn in the study sites may be attributed with both cement- related deposition and other activities around the plant. Cement manufacturing generate particulate matter during quarrying, crushing and grinding of raw materials, kiln operation, processing, storage and transportation of cement and raw materials. Zn associated with cement particles can be transported through the atmosphere and deposited on surrounding soils by dry deposition and rainfall (Yahaya et al., 2023). Furthermore, Zn in soil is associated with vehicular emissions, including mechanical anomalies and abrasion of vulcanized tyres, as the study area is linked with the movement of trucks associated with cement production and transportation (Kolo et al., 2018). The level of Zn in this study was higher than those reported by Yahaya et al. (2023) and Kolo et al. (2018) for soil around a cement plant in Northwestern and North eastern part of Nigeria, respectively but lower than values reported by Gržetić and Ghariani (2008) for soil around a cement facility in Belgrade, Serbia.

The presence of Ba in the study soils may be partly due to the raw materials and cement additives used during the cement processing. Barium compounds have been reported as mineralizer or raw material additives in specialized cement processing (Zezulova et al., 2016). This could be responsible for its presence in the study sites. Similar to Zn, Ba associated with fine particulate matter may be transported from the cement plant and deposited on nearby soils. The extent of deposition can vary according to particle size, atmospheric condition, distance from the emission source and prevailing wind direction. Sulaiman et al. (2024) reported lower Ba in soil investigated around a cement factory in Bajoja, Nigeria.

Nickel occurs naturally in soil, it is an important micronutrient for some plants (Abdulsalam et al., 2021a; Abdulsalam et al., 2021b). Ni concentration observed in the sampling sites could reflect natural soil sources and inputs from human activities around the cement facility. Cement production and the associated handling and transportation of raw materials can generate dust containing trace elements which may be transported and deposited on nearby soils. The movement of heavy duty trucks around the facility may contribute to Ni inputs through fuel combustion, vehicle emissions and the resuspension of contaminated road dust (Kolo et al., 2018). Lower Ni values were documented by Asher et al. (2020) and Addo et al. (2012) for soil around a cement plant in North

Central, Nigeria and the Volta region, Ghana respectively. Higher Ni was reported by Schuhmacher et al. (2004) for soil around a cement facility in Catalonia, Spain.

Titanium is a naturally lithogenic element that is commonly associated with several raw materials used in cement production including clay shale, and limestone, and may be present in cement dust released during processing. Its presence in the study area may therefore largely reflect the mineral composition of the parent materials and raw materials processed in the cement plant.Coal combustion and other fuels can contribute to the release of Ti particles which can get incorporated with the cement related dust particles and subsequently get deposited on the surrounding soils (Sulaiman et al., 2024). Higher Ti values were documented by Mandal and Voutchkov (2011) for soil around a cement plant in Rockfort Kingston, Jamaica, while Sulaiman et al. (2024) reported lower Ti values for soil around a cement facility in Gombe, Nigeria, in comparison with the concentration of Ti in this study.

Soil contamination indices

Enrichment factor (EF)

The mean EF value for Ni fell in the class of no enrichment, whereas those of Zn, except for site A that fell in the class of moderate enrichment, Ca, and Ba were in the class of minor enrichment. An EF value below 1.5 generally indicates that the presence of an element is mainly related to natural or geogenic sources, whereas higher values may indicate some contribution from human activities (Abdulsalam et al., 2026). The lack of enrichment observed for Ni suggests that its concentration in the study soils is close to the background level and may be largely controlled by natural sources. The minor enrichment of Zn, Ca and Ba, however, suggests that their concentrations have been influenced to some extent by additional inputs. These inputs may be linked with cement production and other human activities around the facility, although the contribution of natural soil-forming processes cannot be ruled out. Overall, the EF results indicate that both natural and human activities may be contributing to the levels of the investigated elements in the study area (Abdulsalam et al., 2026).

Contamination factor (CF)

The CF values showed different levels of contamination across the study sites, ranging from low to considerable contamination. The higher CF values observed for Zn and Ca indicate that these elements were more elevated in the study soils relative to the background concentration. Although such enrichment can be associated with human activities, natural variations in soil composition and geochemical processes may also contribute to the observed levels (Okonkwo et al., 2021).

The relatively high CF values for Zn and Ca indicate enrichment compared with the background soil. However, CF reflects the increase in concentration relative to the selected background value rather than its exceedance of regulatory soil-quality limits. The results from this investigation therefore suggest that Zn and Ca have undergone greater accumulation in the study area, whereas the low CF recorded for Ni indicates comparatively little contamination relative to the background level.

Pollution load index (PLI)

The PLI values showed different levels of pollution across the study sites, ranging from moderate to heavy pollution. Site D was moderately polluted while the other study sites were heavily polluted. The higher PLI values at the sites indicate a greater overall accumulation of the investigated elements compared with the background level. The mean PLI for the study sites also indicated heavy pollution, suggesting that the combined presence of the elements has affected the quality of the soils around the cement plant. Similar findings have been documented in areas around industrial activities (Emurotu et al., 2024). The results highlight the need for regular monitoring of the soils around the facility to identify any further changes in contamination levels.

Geo-accumulation index (Igeo)

The mean Igeo values showed that the soils ranged from unpolluted to moderately polluted. Igeo of Zn and Ca indicates moderately polluted, Ba ranged from unpolluted to moderately polluted, whereas Ni and Ti were in the class of unpolluted. The negative Igeo values for Ti and Ni indicates no significant accumulation relative to the corrected background level. The higher Igeo values recorded for Zn and Ca indicate that these elements have accumulated to a greater extent in the study soils compared with the background level. Their presence may be related to cement production and other activities around the plant, although natural sources may also contribute. The relatively higher contamination observed for Zn and Ca suggests the need for regular monitoring of the soils around the cement facility to detect possible increases in their concentrations over time.

Conclusion

The investigated selected element concentrations in the soil collected around Obajana cement plant revealed that the contents of Zn, Ba, and Ni were within the CCME (2007) guideline limits, while no specific guideline values were available for Ca and Ti. The pollution indices showed the level of metal enrichment in comparison with the control. The higher enrichment observed for Zn, Ca and Ba suggests that activities around the cement facility may have contributed to their presence in the soils, although natural sources may also be involved. Overall, the contamination indices indicated that the soils around the facility have experienced some degree of elemental enrichment and contamination, particularly for Zn and Ca. Regular monitoring of the soil and proper environmental management around the cement facility is necessary to identify possible changes in soil quality over time.

Recommendations

Further studies should be done to examine the concentrations of other potentially toxic elements, including Pb, Cd, As and Cr that were not included in the present study, in edible plants growing in the soil around the study sites, particularly those commonly consumed by the residents. Regular monitoring of the soil around the cement facility is recommended to identify any increase in metal levels over time and support appropriate environmental management strategies.

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Conflict of interest

The authors declare no conflict of interest

Author contribution

Study design: Abdulsalam, S. and Emurotu, J.E.; Data collection: Abdulsalam, S., Sumaila, A. and Evinemi, P.A.; Formal analysis: Abdulsalam, S., Yahaya, R.A. and Sadiku, J.O.; Supervision: Emurotu, J.E.; Writing of original draft: Abdulsalam, S., Yahaya, R.A. and Sadiku, J.O; Writing-review & editing: Abdulsalam, S. and Emurotu, J.E. All authors read and approved the manuscript.

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