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Heavy Metal-Related Health Risk Assessment of Cultivated Plants Around a Cement Factory in Sokoto North Western, Nigeria

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ABSTRACT: The pollution of the environment by cement manufacturing companies is becoming a global concern, particularly in developing nations. This study assessed the levels of heavy metals and their associated health risks in sugarcanes (*Saccharum officinarum*), tomatoes (*Solanum lycopersicum*), and almonds (*Prunus dulcis*) cultivated in the vicinity of a cement factory in Sokoto, Nigeria. Samples of these plants were collected, treated, and then assayed for lead (Pb), copper (Cu), cadmium (Cd), and zinc (Zn) using atomic absorption spectroscopy (AAS). The values obtained were compared against the permissible limits established by the World Health Organization (WHO), and these results were used to estimate the potential health risks associated with consuming these plants. The findings revealed that both the *Solanum lycopersicum* and *Saccharum officinarum* contained non-tolerable levels of Cu, Cd, Pb, and Zn, while *Prunus dulcis* had non-tolerable levels of Zn only. Additionally, the concentrations of individual heavy metals in each of the three plant species showed a significant difference ($p \leq 0.05$) from the respective WHO standards. The estimated daily intake (*EDI*) and target hazard quotient (*THQ*) for all the heavy metals were within the recommended limits, except for the *EDI* of Pb in *Saccharum officinarum* and the *THQ* of Pb in *Solanum lycopersicum*. The health risk index (*HRI*) for all the heavy metals in the three plants exceeded the tolerable limit (> 1). These findings indicate that daily consumption of these plants may pose health hazards. Therefore, the practice of cultivating plants in the vicinity of cement factories should be discouraged.

KEYWORDS: Cement factory; estimated daily intakes; heavy metal pollution; risk assessment

1. Introduction

Cement is the most common and frequently used adhesive in the building industry; it is employed to construct roads, houses, embankments, bridges, offices, etc. [1]. Thus, the cement manufacturing industry plays a vital role in global economic development [2]. In recent years, there has been a substantial surge in cement production, which can be attributed to increased commercialization, urbanization, population growth, and infrastructural development [3]. In 2022, global cement production reached 4.1 billion metric tons, a considerable increase from 1.39 billion tons in 1995 [1, 4]. With the world's population on the rise and industrialization progressing, cement production is projected to escalate by 12-23% by 2050 [5]. Among the top cement-producing nations, China leads as the largest producer, responsible for 59.31% of global cement manufacturing [1]. In Nigeria, an abundance of limestone, coupled with a growing population, has led to the expansion of the cement industry. Nigeria boasts the largest cement industry in West Africa, with at least 12 registered companies, contributing to a combined cement capacity of 58.9 metric tons in 2022 and a projected capacity of 244.1 metric tons by 2025 [6].

Cement is a powder-like substance whose raw materials (limestones and mud-clay) are obtained by blasting rock quarries with explosives [7]. The production of cement releases soot particles and dusty residues, contributing to environmental pollution. Cement dust contains pollutants such as dioxin, heavy metals, and particulate matter [8]. Some other pollutants released during cement production are volatile organic compounds, carbon monoxide, sulfur dioxide, nitrogen oxides, and hydrocarbons [9]. Moreover, cement production accounts for approximately 40% of global carbon dioxide emissions and 7% of greenhouse gases emitted worldwide [10-12]. Among the pollutants in cement dust, heavy metals pose the greatest risk due to their non-biodegradability, persistence, and toxicity, even in minute quantities. Commonly identified heavy metals in cement dust include cadmium (Cd), chromium (Cr), copper (Cu), zinc (Zn), and lead (Pb) [13]. Human exposure to cement pollutants can occur through inhalation, dermal exposure, or ingestion of cement-polluted soil, water, or plants. Exposure to cement dust is associated with various respiratory ailments, such as cough, asthma, and lung infections, as well as allergies and other health complications, including hypertension, diabetes, and backache [14].

To sustain the ongoing expansion of the cement industry, it is imperative to continually monitor the health of both workers and the residents in the vicinity of cement facilities, as well as plants cultivated near these factories. This approach will facilitate early detection of exposure and mitigate its adverse effects. Heavy metals play important roles in plant development by participating in metabolic reactions and serving as micronutrients (e.g., Fe, Co, Cu, Mn, Zn, and Mo). However, when their concentrations exceed certain threshold, they become detrimental to plant growth and development [15]. Moreover, exposed cultivated plants may pose health risks to consumers.

In the northwestern Nigerian city of Sokoto, a cement manufacturing company supplies cement to various regions, making a substantial contribution to the local and national economy. Regrettably, the dust emanating from the company and its quarries pollutes the environment, including nearby cultivated plants. Consequently, it is essential to regularly monitor the plants grown around the cement factory to detect overexposure early, preventing or reducing health hazards. This approach will ensure sustainable growth, allowing the cement company to operate unhindered while safeguarding the health of the local population. Unfortunately, a review of the existing literature reveals a lack of recent pollution assessments at the cement company and no prior assessments of plants grown in the vicinity. This assessment is crucial to raise public awareness if the plants are found to pose health risks. Therefore, the purpose of this study is to determine the levels and health risks associated with heavy metals in selected cultivated plants around the company.

2. Materials and Methods

2.1. Description of the study area

This study was conducted in Kalambaina, Wamakko Local Government Area, Sokoto State, Nigeria. Sokoto is situated in the extreme northwestern Nigeria, located at the confluence of the Sokoto River and the Rima River at latitudes 13° 4' 0'' N and 5° 13' 60'' E [16]. The city is predominantly inhabited by the Hausa and Fulani ethnic groups, with substantial populations of settlers from the Yoruba, Igbo, Nupe, and Tiv tribes. Sokoto experiences an annual average temperature of 28.3 °C, with temperatures occasionally soaring to 47.2 °C during hot weather, making it one of the hottest in Nigeria. The region falls within the savannah zone, characterized by grasslands that are ideal for cultivating grain crops and animal husbandry [17]. Rainfall in Sokoto typically starts late and ends early, with mean annual precipitation ranging from 500 mm to 1,300 mm [17]. The state has two distinct seasons: the dry season (October to May) and the wet season (May to October) [17]. The primary livelihoods of the people in Sokoto revolve around farming, animal rearing, trading, and craftsmanship. Additionally, the Kalambaina area of the state is rich in limestone deposits, prompting some residents to engage in quarrying activities, while others work in a cement company located in the town. These quarrying and cement manufacturing activities have bolstered economic activities in the area, contributing to the economic development of the state and the nation. However, the activities at the quarries and the cement company have resulted in environmental pollution, underscoring the need for this study to assess the suitability of certain plants grown in the area for consumption.

2.2. Sample collection and preparation.

Triplicate samples of sugarcane stems, tomatoes, and almonds were collected monthly in cleaned polyethylene bags from the area surrounding a cement company in Sokoto between July and October 2022. In total, 12 samples of each plant were collected. Each sample was washed separately under running tap water and subsequently rinsed with distilled water to remove any impurity. Following this, they were air-dried at room temperature (25-27 ^{o} C) for a duration of two weeks [18]. Subsequently, the dried materials were ground into a powder form using a pestle and mortar.

2.3. Heavy metals analysis.

The procedures outlined by Yahaya et al. [18] were followed. Precautionary measures were taken before commencing the analysis to obtain accurate results. Specifically, all reagents used were of analytical grade (ANALAR), and all glassware was thoroughly washed with a detergent solution and rinsed with distilled water. After that, five (5) grams of each sample were digested in a beaker containing 10 mL each of nitric and perchloric acids, along with 1 mL of sulfuric acid. The mixture was stirred continuously for a few minutes, after which 5 mL of distilled water were added and stirred again. The resulting solution was filtered into a volumetric flask and transferred into a labeled sample bottle. The solution was filtered using Whatman No. 42 filter paper into another beaker and brought up to the 50-mL mark with distilled water. After thorough mixing, it was left to cool. The levels of Zn, Cu, Pb, and Cd in each sample were subsequently determined using the PG-990 atomic absorption spectrophotometer. Additional precautionary measures were implemented throughout the analysis to ensure the precision of the results. Notably, the background contamination of the samples was regularly checked by testing blank samples concurrently with the samples. Furthermore, each sample was tested three times and the reproducibility of values was consistently above 95%. The instrument's functionality was also monitored using reference materials.

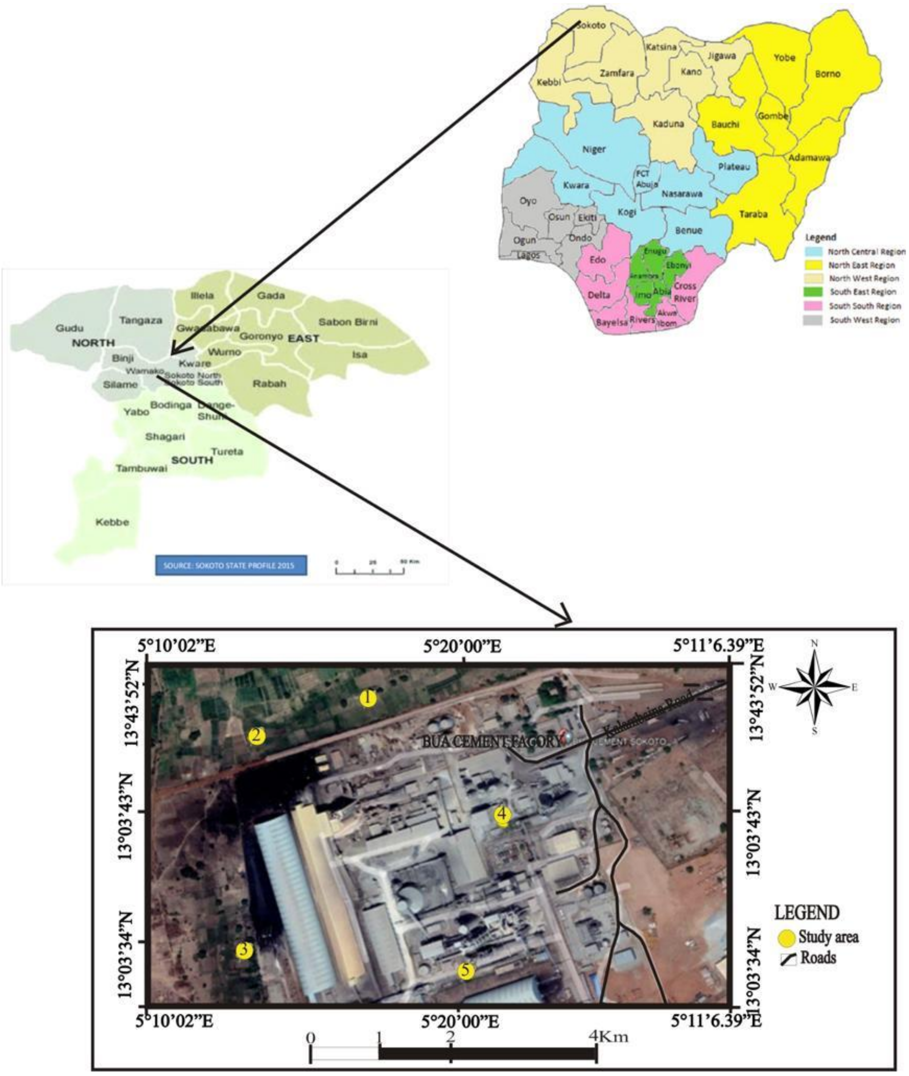

Figure 1. Map of the study area.

2.4. Health risk assessment of the heavy metals.

The risks associated with daily consumption of the plants were estimated from the estimated daily intake (*EDI*), target hazard quotient (*THQ*), and health risk index (*HRI*) of heavy metals in the plants using equations 1, 2, and 3, respectively [19].

$$EDI = \frac{Cn \times CF \times FIR}{ABW} \quad (1)$$

$$THQ = \frac{Cn \times ED \times EF \times FIR}{ABW \times AT \times RFD} \times 10^{-3} \quad (2)$$

$$HRI = \frac{EDI}{RFD} \quad (3)$$

According to USEPA [20], Cn represents the concentration (mg/kg) of heavy metals in the plant samples; CF stands for the conversion factor (0.085); FIR signifies the food ingestion rate (65 g/day); EF denotes exposure frequency (365 days/year); ED represents exposure duration (55 years, which is the average life span of a Nigerian resident); ABW indicates the average body weight of a Nigerian (65 kg); AT is the average exposure time for non-carcinogenic health risk (EF × ED); and RFD is the reference dose for each heavy metal (Zn = 0.3, Cd = 0.001, Cu = 0.04, Pb = 0.0035).

2.5. Data analysis.

The levels of heavy metals in the plants were reported as mean ± standard deviation, utilizing Excel software version 20. The estimated daily intakes (*EDI*), target hazard quotient (*THQ*), and health risk index (*HRI*) for the heavy metals were also computed with the aid of Excel software. Significant differences among variables were assessed using the analysis of variance (ANOVA), where p ≤ was considered statistically significant.

3. Results and Discussion

3.1. Levels of heavy metals in the plants.

Table 1 displays the concentrations of Zn, Cu, Pb, and Cd in sugarcanes, tomatoes, and almonds harvested in the vicinity of the cement company. Both sugarcanes and tomatoes exceeded the permissible limits set by the World Health Organization (WHO) for all the mentioned heavy metals [21]. In contrast, almonds had safe levels of all heavy metals except for Zn. Additionally, the concentrations of individual heavy metals in each of the three plant species showed a significant difference ($p \leq 0.05$) from the respective WHO standards. The surface of the soil serves as a fertile reservoir for heavy metals, which are subsequently absorbed by plants along with water through their roots, followed by transportation through the vascular system [22]. Plant roots play a crucial role in facilitating the entry of heavy metal ions from the soil into plants through mechanisms like phytoextraction, phytostabilization, and rhizofiltration [22]. Zn is primarily transported from the root to the shoot through metal transporters known as ZRT-IRT-like proteins (ZIP), while Cd is transported into plant roots through calcium channels and then to the phloem via ZIP transporters [23]. Pb uptake by roots is mediated through the apoplastic pathway or by calcium channels, and Cu transporter proteins (COPT) are responsible for transporting Cu as Cu (I) into plant shoots and cells [23]. According to Trebolazabala et al. [24], tomato plants have a greater capacity to absorb heavy metals compared to many other plant species, which could explain the elevated concentrations of heavy metals in the plant compared to other plants examined in the current study. Moreover, Zn is one of the most prevalent heavy metals found in soil, which may account for its abundance in all the plants examined in this study [25].

The detection of the heavy metals in the plants aligns with the findings of Warrah *et al*. [26], who reported high levels of Hg, Zn, Cd, Cr, Ni, Pb, and Cu in plants near a cement company in Sokoto, Nigeria. Egbe et al. [27] also found non-tolerable levels of Cr and As in some vegetables cultivated around a cement company in Cross River State, Nigeria. However, these results contrast with those of Nomor et al. [28], who detected permissible levels of Cd and Pb in samples of casava and pawpaw leaves obtained around the Dangote Cement Company in Gboko, Benue State, Nigeria. The inconsistencies observed in these studies may be attributed to variation in pollution control strategies, installed technologies, and energy sources employed by cement companies [9, 29]. Furthermore, the metal-accumulating properties of plants also vary [30], which could contribute to the observed discrepancies.

Table 1. Mean levels (mg/kg) of heavy metals in sugarcanes, tomatoes, and almonds obtained around a cement company in Sokoto.

Plant	Zinc	Cadmium	Copper	Lead
Sugarcanes	16.83 ± 3.98^{a}	0.47 ± 0.02^{a}	10.27 ± 2.21^{a}	2.66 ± 0.68^{a}
Tomatoes	52.77 ± 11.89^{b}	0.50 ± 0.05^{a}	4.74 ± 3.16^{b}	6.06 ± 1.13^{b}
Almonds	14.37 ± 2.98^{c}	0.12 ± 0.04^{b}	2.75 ± 0.89^{c}	1.85 ± 0.44^{c}
Limit [21]	$\mathbf{6.0^{d}}$	$\mathbf{0.2^{c}}$	$\mathbf{4.0^{d}}$	$\mathbf{0.3^{d}}$

Values were expressed as mean ± SD (n = 6); values in the same column with different superscripts (a, b, c, and d) are significant different at $p \leq 0.05$ (ANOVA); WHO: World Health Organization Means that do not share a letter are significantly different.

3.2. Health risk of daily consumption of the plants.

The estimated daily intake (*EDI*) of Zn, Cu, Pb, and Cd from consumption of sugarcanes, tomatoes, and almonds cultivated in the vicinity of the cement company is shown in Figure 2. The *EDI* for all heavy metals fell within the recommended limits, except for Pb in sugarcanes and tomatoes. Figure 3 demonstrates that the target hazard quotient (*THQ*) for all heavy metals also remained within the permissible limits, except for Pb in tomatoes. However, as depicted in Table 4, the health risk index (*HRI*) for each individual heavy metal surpassed the threshold of 1. The obtained results suggest that these plants may not be suitable for consumption, and almonds exhibited the lowest health risks among the three. Excessive uptake of heavy metals can be harmful to the plants themselves or lead to the accumulation of toxic levels in the human body through the food chain [31]. Cd, when ingested, affects various organs, notably the kidneys, lungs, and bones, and has been demonstrated to be carcinogenic [32]. Zn's toxic effects encompass symptoms such as fever, respiratory problems, nausea, chest pain, and cough [33]. Pb accumulates in the brain, liver, kidney, teeth, and bones, posing particular toxicity risks to children [34]. Chronic Cu exposure can lead to conditions such as anemia, liver dysfunction, and neurological problems [35]. Importantly, the *HRI* of the heavy metals indicates that heavy metals within the plants may interact synergistically to induce health effects (Figure 4). This finding aligns with the observations of Egbe et al. [27], who reported permissible *HQ* (< 1) but non-permissible *HRI* (> 1) of heavy metals in vegetables obtained around a cement plant in Cross River State, Nigeria. Yaqub et al. [36] similarly documented non-tolerable *THQ* and *HRI* values for heavy metals in fruits and vegetables obtained near a cement plant in India. However, Safari and Karim [37] found no evidence of heavy metal risk in plants grown around a cement company in Iran. Moreover, Yitagesu and Bekele [38] detected no health risk associated with heavy metals in barley plants cultivated around a cement plant in Ethiopia.

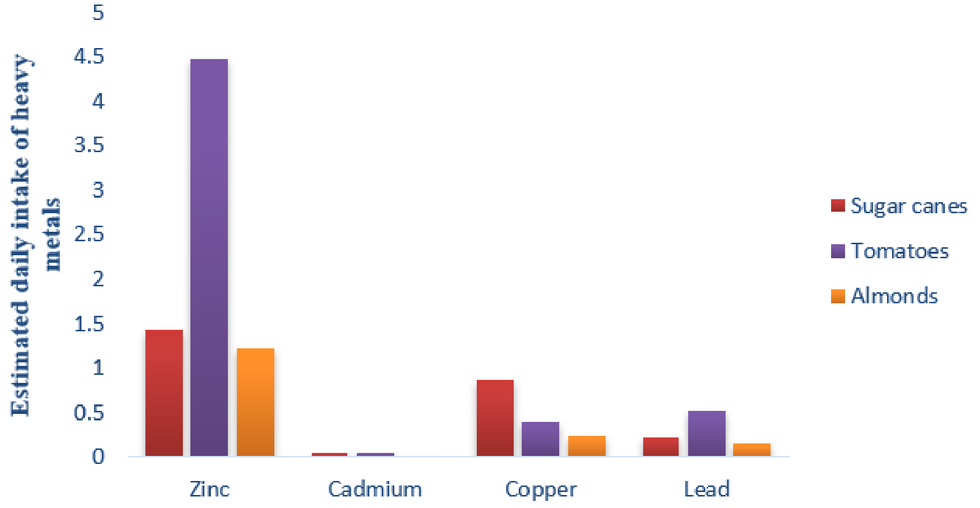

Figure 2. Estimated daily intake (*EDI*) of heavy metals (mg/kg) in sugarcanes, tomatoes, and almonds obtained around a cement company in Sokoto.

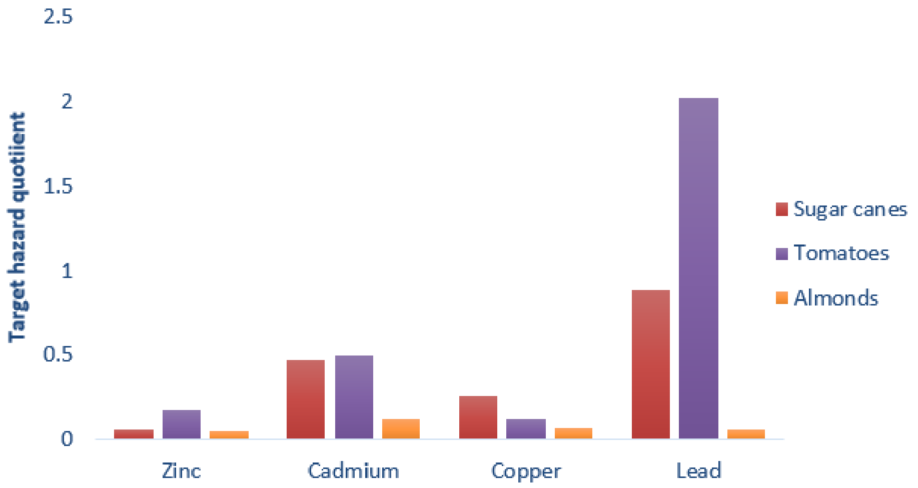

Figure 3. Target hazard quotient (*THQ*) of heavy metals (mg/kg) in sugarcanes, tomatoes, and almonds obtained around a cement company in Sokoto.

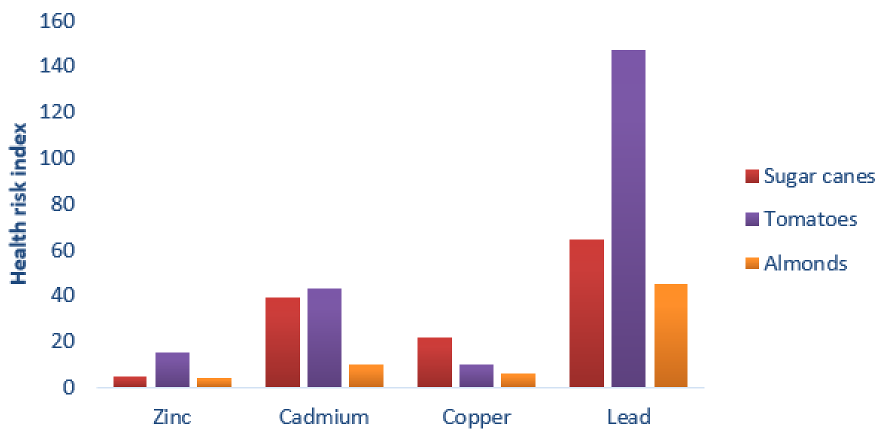

Figure 4. Health risk index (*HRI*) of heavy metals heavy metals (mg/kg) in sugarcanes, tomatoes, and almonds obtained around a cement company in Sokoto.

4. Conclusions

The results revealed that tomatoes and sugarcanes cultivated in the vicinity of the cement company contained levels of Cu, Cd, Pb, and Zn, that exceeded acceptable limits, while almonds exhibited elevated levels of Zn only. The health risk index (HRI) for the heavy metals tested in each of these three plants surpassed permissible thresholds (> 1), indicating that regular consumption of these plants could pose health risks. We recommend that cultivation of plants around the cement factory should be discouraged, and it is crucial for the company to prioritize pollution control measures. Furthermore, additional studies are warranted to corroborate the findings of this study and to encompass a broader spectrum of heavy metals or pollutants not previously examined.

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Competing Interest

All the authors declared no conflict of interest.

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