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Analysis of Heavy Metal Absorption in Plants from Selected Quarry Sites in Osun State, Nigeria

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ABSTRACT

Anthropogenic activities such as mining, quarrying, and industrial operations significantly contribute to environmental contamination by releasing organic and inorganic pollutants. This study examines heavy metal accumulation in plants near three quarry sites in Osun State, Nigeria: Sanlong Quarry (Obaagun), Wolid Quarry (Iwoye), and Jolokun Quarry (Modakeke). Heavy metals analysed include Cadmium (Cd), Arsenic (As), Lead (Pb), Chromium (Cr), Nickel (Ni), Copper (Cu), and Zinc (Zn). Plant leaves were sampled at distances of 0, 15, 30, and 45 metres from quarry sites, with control samples taken 150 metres away. Using Atomic Absorption Spectroscopy (AAS), the analysis revealed elevated levels of Cd, Pb, Cr, Ni, and Zn near all sites, exceeding WHO (1996) permissible limits, while As and Ni were within acceptable ranges. Sanlong Quarry samples showed high concentrations of Cu, Cd, Ni, and Pb, Wolid Quarry samples recorded elevated Zn levels, and Jolokun Quarry samples contained higher Ni and Cu levels. ANOVA results confirmed significant deviations from WHO standards, underscoring contamination risks. These findings raise concerns about environmental and food safety hazards linked to heavy metal accumulation in plants near quarry operations. Immediate mitigation measures are necessary to address these risks and protect environmental health and sustainability.

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INTRODUCTION

The quarry industry has long played a significant role in human development, with its importance and impact evident from ancient times to the present day (Hassan, 2022). In recent years, the industry has expanded due to various factors, including rapid urbanization, technological advancements, and industrial innovations, leading to the extensive exploitation of natural resources such as rocks. This expansion has resulted in a proliferation of quarrying activities, along with their accompanying environmental consequences. Hassan (2022), underscored these developments, while Gideon *et al.* (2022), highlighted the industry's positive contributions to development and urbanization. Likewise, Peter *et al.* (2018); Tombari *et al.* (2021), emphasized the quarry industry's critical role in construction, particularly in producing high-quality stones for building materials and durable components for infrastructure projects such as roads, bridges, railways, and culverts. However, the environmental costs of

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quarrying have drawn increasing attention. Ogbonaya and Phi-Eze (2020); Wahab *et al*. (2022), submitted that most quarrying processes release airborne particles, contributing significantly to environmental pollution and health hazards. These pollutants have been linked to approximately 4 million annual deaths globally, particularly in developing nations where environmental safety regulations are often inadequate. Also, Masindi and Muedi (2018), further highlighted the accumulation of hazardous metals such as Lead, Cadmium, Chromium, Zinc, Mercury, and Arsenic due to quarrying, attributing their prevalence to anthropogenic activities. The challenge is balancing the industry's contributions to development with the urgent need for environmental and health protection.

In addition, recent studies have examined the specific impacts of quarry dust on the environment and human health. Nyapala and Kamwele (2015); Oyinloye and Olofinyo (2017); Mandal and Pal (2020); Kunooz (2022), identified quarry dust as more than fine particles, emphasizing its harmful constituents and adverse effects on air, soil, water, plants, and human health. Kameswaran *et al.* (2019), described the toxic nature of quarry dust, while Amujiri *et al*. (2022), revealed its detrimental effects on plant systems, including reduced productivity and compromised food safety and security. Shamaila *et al.* (2015); Shukla *et al.* (2019), similarly highlighted the negative impacts of quarry dust on plant growth, yield, quality, and market value. The effects on human health are equally concerning. Ibrahim *et al*. (2018); Rajanayagam *et al.* (2023), linked prolonged exposure to quarry dust with severe health conditions, including cancer, pulmonary infections, silicosis, asthma, chronic bronchitis, and blood contamination. Osu (2020), echoed these concerns, documenting the broader implications of quarry dust pollution for living systems and nearby communities.

Furthermore, Tanushree (2023), examined the mechanisms by which quarry dust disperses over long distances, impacting areas far from the source of pollution. He *et al.* (2022); Jahromi *et al.* (2020), stressed that accumulation of heavy metals, such as Cadmium (Cd), Arsenic (As), Lead (Pb), Chromium (Cr), Nickel (Ni), and Mercury (Hg), in plants are major consequences of human-induced pollution. It was further discussed that contamination occurring from mining, quarrying, and industrial operations, are of detrimental effects to the environment and living systems following undue exposure. Also, Thompson and Agbugba (2013), underscored the critical role of plants and vegetables in human nutrition, pointing out that vegetation near quarrying and mining areas are particularly vulnerable to contamination. This observation was corroborated by Omosanya and Ajibade (2011); Ming'ate and Mohamed (2016), who documented the presence of toxic metals such as Cd, Pb, Cr, Zn, and Ni in edible vegetables, raising concerns about their implications for food safety.

Similarly, Hasanuzzaman *et al.* (2013), established that vegetation under environmentally stressed conditions undergoes significant physiological and biochemical changes, leading to malformations such as stunted growth, nutrient deficiencies, poor water distribution, enzyme dysfunction, oxidative stress, chlorophyll deficiencies, necrosis, and impaired stomatal function. These findings highlight the ongoing trend of metal accumulation in the food chain and its far-reaching consequences for plants and living organisms. Given these environmental challenges, this study investigates the absorption of heavy metals by plants located in polluted areas, particularly near quarry sites, through detailed laboratory analyses.

The study objectives are to:

1. Assess the eco-friendliness of quarry deposits on invasive plants from three quarry sites (Obaagun, Iwoye, and Jolokun) in Osun State, Nigeria.

2. Determine the concentrations of heavy metals in the examined plants from the selected quarries and compare the results with relevant standards to evaluate the suitability of adjacent economic plants for various purposes.

3. Identify similarities and variations in heavy metal concentrations across the investigated quarry sites.

METHODS OF STUDY

Brief Overview of Osun State

Osun State, one of Nigeria's thirty-six states, was created in August 1991 following its separation from Oyo State. It is located in the southwestern region of Nigeria, covering an area of approximately 14,875 square kilometers (Britannica, 2024). Geographically, Osun State lies at a latitude of 7° 30′ N and a longitude of 4° 30′ E (Geographical Profile of Osun State). The state is endowed with abundant rivers, streams, and rock formations (Geographical Survey of Nigeria, 2024). The name "Osun" is derived from a prominent deity in the region and is closely associated with water sources, reflecting the state's rich water resources (Britannica, 2024). The State lies between the tropical rainforest belt in the southern part of Nigeria. The head count conducted in 2006 showed that Osun State had a total population of Three million, four hundred and twenty-three thousand, five hundred thirty-five. By 2014, the population had increased to Four million, four hundred and forty-nine thousand, three hundred and nineteen as reported by the United Nations Population Fund (UNFPA, 2014). The state is characterized by numerous hills and rocky areas, particularly in towns such as Ilesa, Ikirun, Iwoye, Obaagun, Eripa, Ile-Ife, Modakeke, Ikire, and Gbongan. Historically, these hills have served as shelters and provided defense during conflicts, including those between the Yoruba and the Fulani regime (Britannica, 2024; Geographical Profile of Osun State).

The Study Areas

This study was conducted in Osun State, Nigeria, focusing on three quarries selected from different senatorial districts: Osun Central, Osun East, and Osun West. The specific quarry sites examined were:

Sanlong Quarry Industry, located in Obaagun (Osun Central).
Wolid Quarry Limited, situated in Iwoye (Osun West).
Jolokun Quarry Industry, located in Modakeke (Osun East).

Overview of Sanlong Quarry Industry

Sanlong Quarry Industry is a large-scale, privately owned enterprise located along the Ikirun/Iree Road in Obaagun, within the Ifelodun Local Government Area of Osun State. Obaagun is situated at a latitude of 7° 05' 0" North and a longitude of 4° 40' 0" East, with neighbouring towns including Ikirun, Iragbiji, Oke-Iba, Eweta, and Iree. The Quarry Industry covers an extensive area of 30 acres, which was acquired through joint agreements with various local families. Established in 2019, Sanlong Quarry received official authorization from the Osun State Government to conduct mining operations in this region, which is rich in rock deposits. Since its establishment, the quarry has been actively engaged in rock mining and processing.

Moreover, Sanlong Quarry produces a range of high-quality rock products, including granite, sandstone, stone dust, stone base, marble, crushed stones, and dimensional stones in various sizes. The quarry is substantial in size and consists of multiple compartments, requiring considerable human labour and contributing to local employment. The workforce is estimated to comprise around 50 personnel, including security staff, crushing plant operators, drillers, mechanics, loaders, rock blasting operators, miners, drivers, front desk secretaries, and others. The quarry operates on a daily basis due to the high demand for its products. The workforce includes both regular and casual employees, with regular staff making up the majority. To facilitate its operations, Sanlong Quarry employs advanced machinery and equipment, such as drilling and crushing plants, tractors, pin loaders, excavators, power generators, and a variety of trucks for product transport. Also, the industry supports the local economy by providing various on-site business opportunities, including food vendors, clothing retailers, grocery stores, and beverage sellers.

However, the quarry's operations exert considerable pressure on the local environment. The emission of heavy metals from mining activities is deposited on nearby plants, causing harm to their health. Over time, this contamination poses potential risks to human health, particularly when consumers unknowingly consume contaminated edible plants.

Overview of Wolid Quarry Industry

Wolid Quarry Industry is a privately owned enterprise situated along the Old Iwo/Osogbo Road in Iwoye, Osun State. Established in 1989, within the Egbedore Local Government Area. Iwoye, located at coordinates 7° 45' 0" North and 4° 22' 0" East, is renowned for its rich rock resources, which have led to the incessant quarry operations in the region. These abundant deposits have become a key driver for ongoing quarry activities, positioning the town as a hub for the industry. Among the numerous quarries in Iwoye, Wolid Quarry Limited is one of the largest. The quarry operates on a semi-large scale, covering an area of approximately 15 to 20 acres. While significant, Wolid Quarry is relatively smaller compared to Sanlong Quarry Industry in Obaagun. Established in 2015 and managed by Wolid Limited, The Quarry's operations are currently concentrated within the main premises.

In addition, the quarry employs a workforce of approximately 40 personnel, including miners, drillers, blasting specialists, drivers, engineers, security staff, crushers, loaders, receptionists, and mechanics. The workforce consists of both regular and casual employees, with the majority being full-time staff. Despite its consistent operations, Wolid Quarry's scale is not as extensive as that of Sanlong Quarry. Also, Wolid Quarry produces a variety of high-quality rock materials, such as granite, crushed and dimensional stones, stone dust, stone base, sandstone, and aggregates like half-inch and three-quarter inch stones. The quarry utilizes advanced machinery, including excavators, loaders, tractors, drilling and blasting equipment, crushing plants, power generators, and heavy trucks.

However, the presence of Wolid Quarry has notably increased Iwoye's commercial profile, attracting business from a wide range of customers. However, research suggests that quarrying in the area may pose potential environmental risks to the surrounding ecosystem.

Overview of Jolokun Quarry Industry

Jolokun is a town located along the Modakeke/Ife Road in Modakeke, Osun State, Nigeria. This suburban area, part of southwestern Nigeria, falls under the jurisdiction of the Ife East Local Government Area of Osun State. The residents of Modakeke, commonly referred to as "Akoraye," are known for their strong cultural identity. Geographically, Modakeke is situated at a latitude of 7° 27' 19.6704" N and a longitude of 4° 32' 39.8112" E. Jolokun Quarry is located in Jolokun Village along the Ile-Ife/Modakeke Road, with neighbouring villages such as Alaro and London Arena.The quarry is a privately owned enterprise managed by a group of individuals. It operates on a relatively small scale, covering approximately three acres of land. Compared to larger quarries like Sanlong and Wolid, Jolokun Quarry has fewer operational sections. The quarry employs a modest workforce of about ten personnel, which reflects its smaller scale of operations. These operations are infrequent and primarily driven by product demand.

Moreover, the products offered by Jolokun Quarry include dimensional and crushed stones,

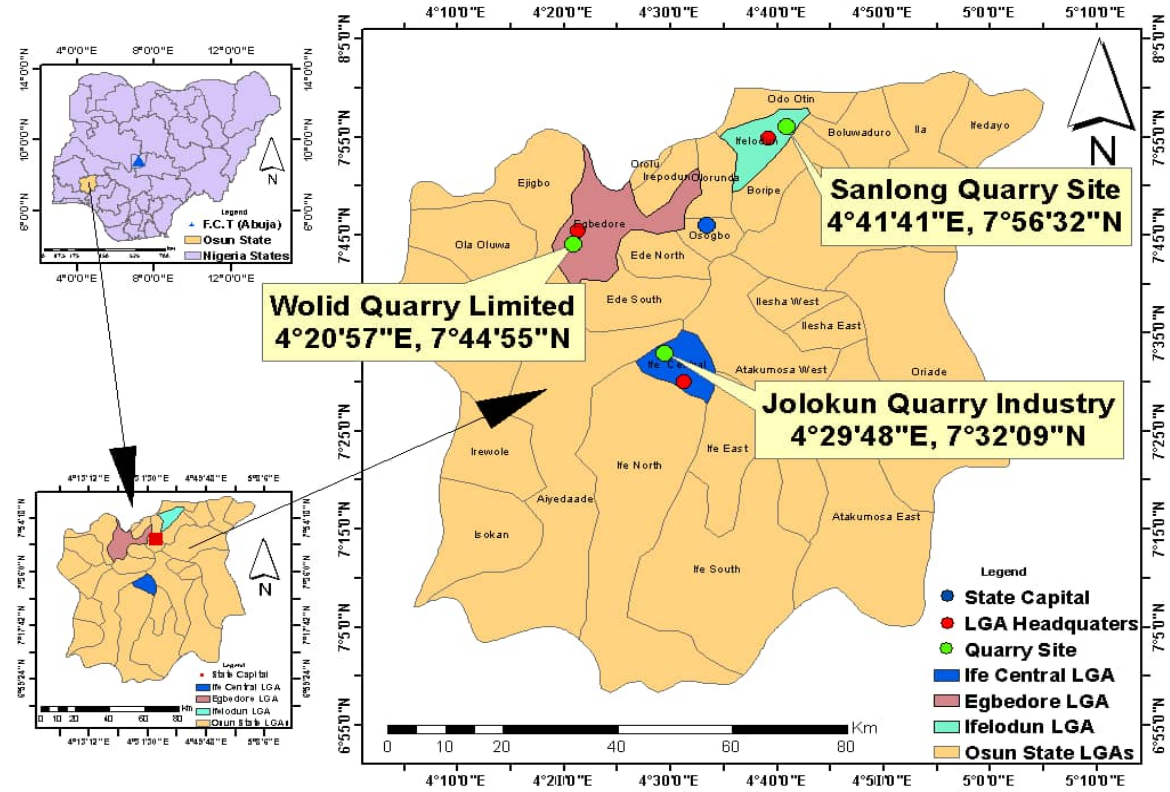

Fig. 1. Location Map of the three Quarries investigated (Source: Field Survey, 2023).

available in various sizes such as half-inch, three-quarter-inch, and hardcore stones. Machinery is predominantly used for drilling and crushing, with other tasks carried out manually. The equipment utilized includes drilling and blasting machines, excavators, hand-breaking tools, loading containers, and mini trucks. Casual staff are frequently employed for many of the quarry's operations. Despite its smaller scale, Jolokun Quarry plays a significant role in the local industry, producing durable rock materials. The study locations and their coordinates are presented below (as shown in figure 1).

Plant Sampling Procedures

Preliminary visits to the quarry sites identified *Chromolaena odorata* (commonly known as Akintola), *Euphorbia hirta* (Milk Plant), and *Helianthus annuus* L. (Sunflower) as the predominant plant species. These species were selected for further elemental analysis, based on their prevalence and suitability for detecting potential environmental contaminants in the area (Thomas *et al.,* 2019; Smith and Jones, 2021)

Plant/Leaf Collection Procedures

Leaves of test plants were systematically collected from three quarry core sites on 22nd, 23rd, and 24th August 2023, during daylight hours. Each site was carefully marked using pegs and measuring tape, ensuring consistent sampling across sites according to Jones *et al.* (2020). Leaves from the selected plant species were collected along predetermined transects at distances of 0m, 15m, 30m, and 45m from the quarry core areas. Control samples were also taken from a location 150m away from the active quarry zones, providing a baseline for comparison (Moe *et al.,* 2018). The coordinates of all sampling points were recorded in real-time (as shown in table 1)

Table 1. Quarries explored and their coordinates

Spot Distances	Sanlong Coordinates for Plant Samples Collection	Wolid Coordinates for Plant Samples Collection	Jolokun Coordinates for Plant Samples Collection
0M	7° 56' 30" 3N 4° 39' 42.8"E	7° 44' 40"8N 4° 20' 49.6"E	7° 28' 29."5 N 4° 27' 33.2"E
15M	7° 56' 32".9N 4° 41' 41".5E	7° 44' 41".2N 4° 20 ' 49".6 E	7° 28' 09".2N 4° 29 ' 43".0 E
30M	7° 56' 06" 9N 4° 41' 38.3"E	7° 44' 39".1N 4° 20' 49.8"E	7° 28' 09".0 N 4° 29' 43.1"E
45M	7° 56' 06" 2N 4° 41' 36.1"E	7° 44' 53".0N 4° 20' 54.9"E	7° 28 09". 1N 4° 29' 44 .2 "E
150M	7° 56' 09" 3N 4° 41' 40.1"E	7° 44' 59".1N 4° 20' 58.9"E	7° 32 09". 2N 4° 29' 48 .2 "E

The plant leaves were harvested manually and stored in labelled polythene bags to ensure proper identification and prevent contamination (Liu *et al.,* 2021). Immediately following collection, the samples were transported under optimal conditions to the Bowen University Central Laboratory for subsequent Atomic Absorption Spectroscopy (AAS) analysis. The leaves of plant samples were then analyzed to determine the presence of seven metals: Cadmium (Cd), Chromium (Cr), Arsenic (As), Nickel (Ni), Lead (Pb), Zinc (Zn), and Copper (Cu), following standard protocols for heavy metal analysis in plant tissues (Zhang and Wang, 2020; Hassan *et al.,* 2022).

Plant Sample Digestion Procedures

The digestion of plant leaves samples was conducted following the procedures outlined by Awofolu (2005). Initially, 0.5 g of powdered plant samples was weighed and placed into a 100 cm^3 beaker. To this, 5 cm^3 of concentrated nitric acid (HNO_3) and 2 cm^3 of perchloric acid ($HClO_4$), along with a few boiling chips, were added. The mixture was then heated to 70°C for 15 minutes until a light-colored solution was obtained. Throughout the digestion process, care was taken to prevent the sample solution from drying out. After digestion, the samples were filtered into a 50 cm^3 standard flask. The beaker was rinsed twice with 5 cm^3 portions of distilled water, and these rinsing solutions were also filtered into the 50 cm^3 flask. The filtrate was allowed to cool to room temperature and was then diluted to the mark. The mixture was thoroughly shaken to ensure proper mixing. The final digest was analyzed using the PG 990 atomic absorption spectrometer (AAS) for the presence of heavy metals.

Data Analysis

The heavy metal concentrations in the leaves of test plants were assessed through laboratory analysis, using statistical tools such as descriptive analysis and analysis of variance (ANOVA). The means were separated using the Duncan Multiple Range Test (DMRT). The results were presented in tables to support the findings. Studies by Akpambang *et al.* (2022); Muhammad *et al.* (2024); have successfully utilized ANOVA and DMRT in heavy metal research, addressing environmental pollution and advancing knowledge in the field. These methods contribute to a broader understanding of the environmental impacts of heavy metals and promote the pursuit of sustainable and livable environment.

RESULTS AND DISCUSSION

I. Heavy Metal Distribution with Respect to Spot Distances (Refer to Figure 2)

Figure 2 illustrates the concentrations of heavy metals in plant leaves sampled at varying distances from quarries, measured in parts per million (ppm). The metal content showed a decreasing trend from Spot A (0 metres) to Spot E (150 metres), with Spot A exhibiting the highest absorption and Spot E the lowest. Metal absorption followed the order: Cd > Pb > Cu > Ni, while Zn, As, and Cr concentrations remained within the limits recommended by the World

Table 2. Mean Concentration of Heavy Metals in Quarry Plants by Spot Distances (Right); Mean Concentration of Heavy Metals across study locations: (Left)

S/N	Heavy Metals	Spot A (0M)	Spot B (15M)	Spot C (30M)	Spot D (45M)	Spot E (150M)	WHO (1996) Standard mg/kg	Result	Sanlong Quarry Industry, Obaagun, Osun - Central	Wolid Quarry Limited, Iwoye, Osun- West	Jolokun Quarry Industry, Modakekeke Osun –East	Implications
1.	Cadmium (Cd)	23..80±74.43^{b}	4.69±22.64^{a}	.852±2.51^{a}	.622±1.92^{a}	.189± .558^{a}	0.02	All spots are greater than WHO standard	14.20 ±53.20^{a}	2.97 ±17.08^{a}	4.99± 30.68^{a}	High cadmium levels at all sites, especially in Sanlong Quarry, could lead to significant health risks such as kidney damage and cancer over prolonged exposure.
2.	Chromium (Cr)	12.96±46.16^{a}	5.77±25.28^{a}	5.18±24.28^{a}	5.06±24.17^{a}	.215± .706^{a}	1-30	Within permissible limit	3.23 ± 18.00^{ab}	13.30 ± 44.25^{b}	.973 ± 3.38^{a}	Chromium levels are within the acceptable limit
3.	**Zinc (Zn)	16.17±61.15^{a}	10.96±54.02^{a}	.826±2.42^{a}	.615±1.92^{a}	.185± .637^{a}	60	All spots are within WHO limit	.727 ± 2.69^{a}	13.39 ± 60.62^{a}	3.14 ± 17.90^{a}	Zinc contents across all spots and locations were within permissible limit for Zn level in plants. However, elevated zinc levels across all spots can lead to toxicity in aquatic life and soil microorganisms, and long-term exposure cause gastrointestinal issues in humans.
4.	Nickel (Ni)	20.09±59.10^{a}	19.20±56.25^{a}	10.07±34.37^{a}	2.59±.499^{a}	.834±.160^{a}	10	Spot A, B and C are > than permissible limits while D and E are < than the recommended limit with Sanlong Quarry exceeding WHO (1996)	11.93 ± 44.96^{a}	9.68± 42.57^{a}	8.68± 31.96^{a}	High nickel concentrations, particularly in Sanlong Quarry can be hazardous, leading to lung cancer and kidney damage, following prolonged exposure.
5.	Arsenic (As)	20.04 ± 62.40^{a}	15.04±51.26^{a}	8.504±41.03^{a}	.704±2.05^{a}	.263± .799^{a}	5- 20	Within permissible limit	10.14 ± 50.71^{a}	6.88 ± 31.53^{a}	5.99 ±34.34^{a}	Arsenic levels are within permissible limit, however, elevated level poses potential risks for long-term exposure, such as skin lesions and cancer
6.	Copper (Cu)	20.67±73.51^{a}	15.23±56.92^{a}	.893±41.03^{a}	.704±2.05^{a}	.263± .799^{a}	10	Spot A and B are > than the REL while others are within the limit	14.26 ± 65.54^{a}	1.09 ± 4.53^{a}	6.89 ± 30.50^{a}	Elevated copper levels in Sanlong Quarry may cause water contamination and pose health risks such as liver and kidney damage with prolonged exposure.
7.	Lead (Pb)	22.63±66.80^{b}	6.37±29.28^{b}	.693±2.02^{a}	.407±1.30^{a}	.200±.584^{a}	2	Spot A and B are > than REL while C, D and E are < than the REL	7.17 ± 32.52^{a}	6.39 ± 38.88^{a}	4.63 ± 28.32^{a}	High lead concentrations, especially in the three Quarries, can lead to neurological damage, developmental issues in children, and cardiovascular problems

Values are presented as means ± standard deviation of three replicates. Different superscript letters within the same column indicate significant differences at $p < 0.05$, as determined by the Duncan Multiple Range Test (DMRT)

Table 3. FAO/WHO Guidelines for Metals in Foods and Vegetables

Metals (mg/kg)	WHO/FAO	NAFDAC	EC/CODEX	Normal Range in Plant
Cd	1	–	0.2	<2.4
Cu	30	20	0.3	2.5
Pb	2	2	0.3	0.50–30
Zn	60	50	<50	20–100
Fe	48	–	–	400–500
Ni	–	–	–	0.02–50

****Source**: Opaluwa *et al.* (2012) (for Zinc contents in plants/vegetables clarification

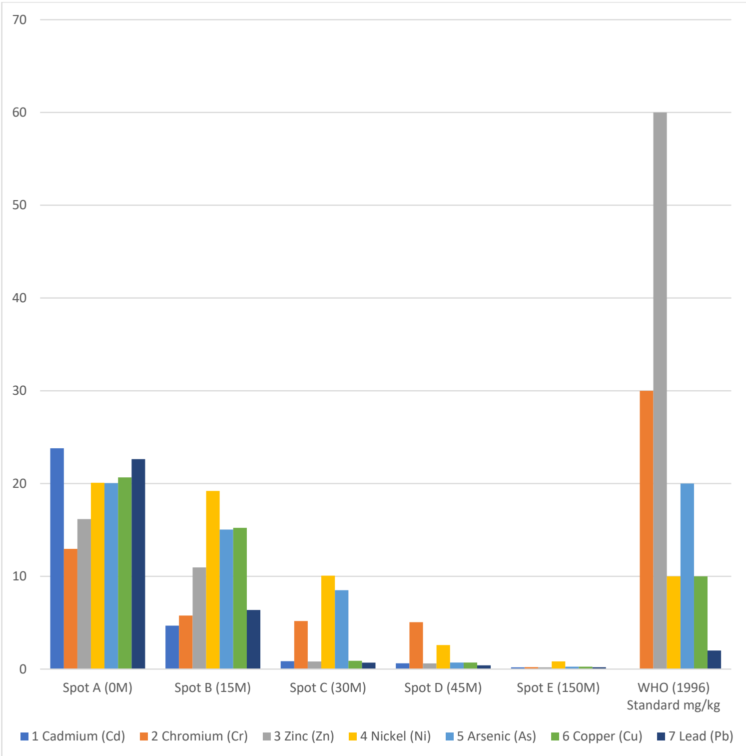

Fig. 2. Heavy Metals Concentration in Plants by Spot locations
Source: Field Survey, 2023

Health Organization (WHO, 1996). These variations reflect the impact of quarry activities on metal content in nearby plants.

Detailed Observations:

i. Cadmium (Cd): Significantly elevated levels were observed across all spots, with the highest concentration recorded at Sanlong Quarry. These levels exceeded WHO tolerable limits.
ii. Lead (Pb): Notably high concentrations were observed at Spots A and B, with Sanlong Quarry exhibiting the peak levels.
iii. Copper (Cu): High concentrations were prevalent at Spots A and B, particularly in plants sampled from Sanlong Quarry in Obaagun.
iv. Nickel (Ni): Elevated levels were detected at Spots A, B, and C, with Sanlong Quarry showing the highest accumulation.
v. Zinc (Zn), Arsenic (As), and Chromium (Cr): These metals were present in lower concentrations within WHO (1996) recommended limits.

Heavy Metal Distribution by Study Locations (Refer to Figure 3)

Figure 3 compares metal absorption across three quarries:

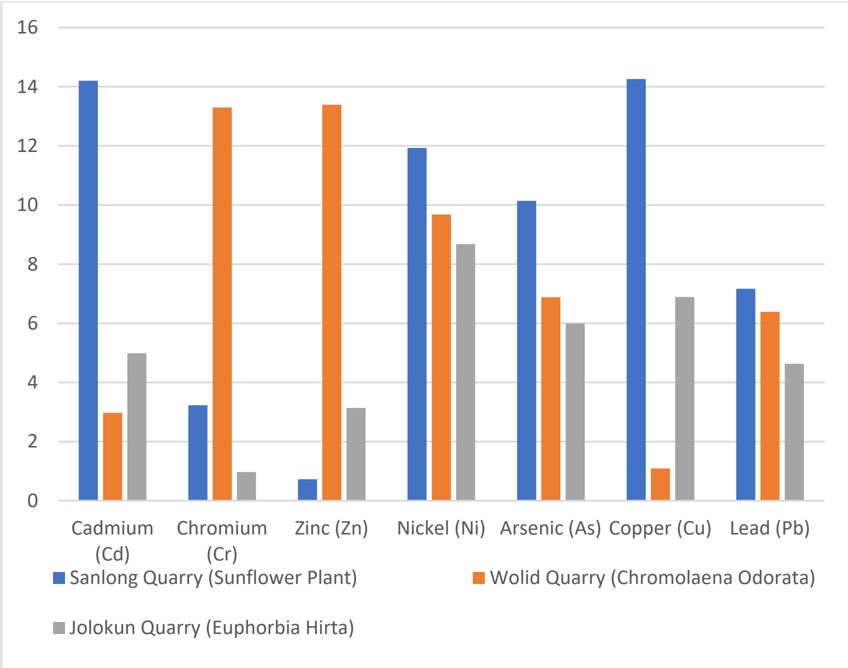

Fig 3. Heavy Metal Assessment of Plants in the Studied locations
Source: Field Survey, 2023.

i. Sanlong Quarry: Plants exhibited the highest levels of Cd, Cu, Ni, and Pb.
ii. Wolid Quarry: High levels of Zn were observed.
iii. Jolokun Quarry: Moderate levels of Cd, Cu, Ni, and Pb were detected, second only to Sanlong Quarry.

Concentration Summary:

i. Cadmium (Cd): Sanlong (14.20 ± 53.20 ppm) > Jolokun (4.99 ± 30.68 ppm) > Wolid (2.97 ± 17.08 ppm).
ii. Zinc (Zn): Wolid (13.39 ± 60.62 ppm) > Jolokun (3.14 ± 17.90 ppm) > Sanlong (3.23 ± 18.00 ppm).
iii. Nickel (Ni): Sanlong (11.93 ± 44.96 ppm) > Wolid (9.68 ± 42.57 ppm) > Jolokun (8.68 ± 31.96 ppm).
iv. Copper (Cu): Sanlong (14.26 ± 65.54 ppm) > Jolokun (6.89 ± 30.50 ppm) > Wolid (1.09 ± 4.53 ppm).
v. Lead (Pb): Sanlong (7.17 ± 32.52 ppm) > Wolid (6.39 ± 38.88 ppm) > Jolokun (4.63 ± 28.32 ppm).

Concentrations of Zn, As, and Cr were within WHO limits.

The findings highlight significant environmental and public health risks associated with quarry operations, particularly the elevated levels of cadmium (Cd). Consistent with previous studies (e.g., Ali et al., 2020; Vijayakumar et al., 2021), quarrying activities were identified as major sources of heavy metal contamination.

Cadmium (Cd): This metal lacks biological utility and poses toxicity risks even at low levels (El Rasaf et al., 2022). Studies (e.g., Aprile and De Bellis, 2020) emphasise its carcinogenic potential and capacity to enter the food chain. Accumulation in consumable plant parts, as reported by Rabelo et al. (2020), compromises food safety.

Copper (Cu): While essential for photosynthesis and metabolic functions (Seeda et al., 2020), excessive copper levels can induce oxidative stress (Htwe et al., 2020) and migrate into foods, posing health risks (Alengebawy et al., 2021).

Nickel (Ni): Known for its environmental abundance, Ni exposure has been linked to severe health issues, including developmental defects (Chen et al., 2018) and carcinogenic effects (Genchi et al., 2020).

Lead (Pb): A hazardous bioaccumulative metal, Pb exposure disrupts cardiac and organ functions and impairs child development (Charkiewicz and Backstrand, 2020; Zhou et al., 2020).

Zinc (Zn): Although critical for enzymatic functions (Wuana and Okieimen, 2011), excessive Zn can lead to health disturbances such as metal fume fever (Plum et al., 2010).

The study underscores the urgent need for environmental safeguards to mitigate heavy metal contamination. Such measures align with Sustainable Development Goals (SDGs) 11 and 15, which advocate for sustainable cities and the protection of ecosystems. Addressing anthropogenic pollution through stringent regulations is essential to foster a healthier environment and achieve global sustainability objectives.

II. Analysis of Variance for Plants by Spot Distances

Table 4 presents the analysis of variance (ANOVA) results for the plants, grouped by spot distances. The results indicated that the p-values were greater than 0.05, suggesting that there is no statistically significant difference between the groups. In other words, no significant correlation exists between the different metals across the sampling spots. Given that the p-values exceeded 0.05, the null hypothesis is accepted, while the alternative hypothesis is rejected.

III. Analysis of Variance for Plants by Site Location

Table 5 presents the analysis of variance (ANOVA) results for the plants, grouped by site location. The results showed that the p-values were greater than 0.05, indicating that the

Table 4. Analysis of Variance of Heavy Metals by Spot Distance

S/N	Heavy Metals	Sum of Squares	df	Mean squares	f	Sig
1	**Cadmium (Cd)**					
	Between Groups	11009.092	4	2752.273	2.270	0.065
	Within Groups	157631.419	130	1212.549		
	Total	168640.511	134			
2	**Chromium**					
	Between Groups	2251.414	4	562.853	.714	.584
	Within Groups	102533.233	130	788.717		
	Total	104784.646	134			
3	**Zinc**					
	Between Groups	5865.132	4	1466.283	1.093	.363
	Within Groups	174326.465	130	1340.973		
	Total	180191.597	134			
4	**Nickel**					
	Between Groups	9845.543	4	2461.386	1.569	.187
	Within Groups	203995.506	130	1569.196		
	Total	213841.049	134			
5	**Arsenic**					
	Between Groups	8589.690	4	2147.422	1.308	.270
	Within Groups	213424.345	130	1641.726		
	Total	222014.035	134			
6	**Copper**					
	Between Groups	9754.200	4	2438.550	1.409	.235
	Within Groups	224969.741	130	1730.536		
	Total	234723.941	134			
7	**Lead**					
	Between Groups	9985.537	4	2496.384	2.343	.058
	Within Groups	138484.180	130	1065.263		
	Total	148469.717	134			

Table 5. Analysis of Variance of Heavy Metals by Site Location

S/N	Heavy Metals	Sum of Squares	df	Mean squares	f	Sig
1	**Cadmium (Cd)**					
	Between Groups	1229.767	2	614.883	.485	.617
	Within Groups	167410.744	132	1268.263		
	Total	168640.511	134			
2	**Chromium**					
	Between Groups	3880.431	2	1940.216	2.538	.083
	Within Groups	100904.215	132	764.426		
	Total	104784.646	134			
3	**Zinc**					
	Between Groups	4068.982	2	2034.491	1.525	.221
	Within Groups	176122.616	132	1334.262		
	Total	180191.597	134			
4	**Nickel**					
	Between Groups	249.676	2	124.838	.077	.926
	Within Groups	213591.373	132	1618.116		
	Total	213841.049	134			
5	**Arsenic**					
	Between Groups	1858.169	2	929.085	.557	.574
	Within Groups	220155.866	132	1667.847		
	Total	222014.035	134			
6	**Copper**					
	Between Groups	3882.081	2	1941.041	1.110	.333
	Within Groups	230841.860	132	1748.802		
	Total	234723.941	134			
7	**Lead**					
	Between Groups	152.872	2	76.436	.068	.934
	Within Groups	148316.845	132	1123.612		
	Total	148469.717	134			

differences between the groups were not statistically significant. Therefore, no significant correlation exists between the plant samples from different sites. As the p-values exceed 0.05, the null hypothesis is accepted, and the alternative hypothesis is rejected.

CONCLUSION

The environmental impacts of Sanlong Quarry Industry (Obaagun), Wolid Quarry Limited (Iwoye), and Jolokun Quarry Industry (Modakeke) in Osun State, Nigeria, were assessed through a comprehensive evaluation of plant leaves metal interactions. This study focused on seven metals: cadmium (Cd), chromium (Cr), nickel (Ni), arsenic (As), zinc (Zn), lead (Pb), and copper (Cu). Laboratory analysis using Atomic Absorption Spectroscopy (AAS) revealed varying levels of heavy metal contamination in plants across the quarry sites. Results showed particularly high concentrations of Cd (23.80±74.43b), Pb (22.63±66.80b), Cu (20.67±73.51a), Ni (20.09±59.10a), and Zn (16.17±61.15a) at Spot A, which exceeded the World Health Organization (WHO, 1996) permissible limits for metal content in plants. Although these metals were also present at elevated levels in other spots, As and Cr remained within acceptable limits as per WHO standards. The findings demonstrate that quarry operations significantly contribute to the contamination of plant habitats, leading to heavy metal accumulation in soil and vegetation.

However, Plants, being integral to ecosystems, serve as a primary source of nutrients, medicinal herbs, animal forage, and pharmaceutical raw materials. Essential elements like Cu, Zn, Ni, and others are vital for plant physiological processes, but they pose severe risks to plant health and ecosystems when present in excessive amounts. Metals such as Cd, Pb, and As are particularly hazardous due to their toxicity and potential for bioaccumulation. This study therefore underscores the ecological pressures posed by quarrying, highlighting the risks of food chain contamination and the associated health implications for living systems. Prolonged exposure to contaminated plants disrupts food safety and security, thereby undermining sustainable environment. To mitigate these risks, stringent environmental monitoring and effective management strategies are crucial for promoting ecological balance and ensuring long-term sustainability.

RECOMMENDATIONS

To enhance environmental sustainability, this study advocates for intensive efforts to raise awareness among quarry workers and neighbouring communities about the health hazards posed by natural resource extraction near industrial zones. Awareness campaigns should focus on the risks of plant contamination by heavy metals such as cadmium (Cd), nickel (Ni), arsenic (As), lead (Pb), copper (Cu), and zinc (Zn). These metals were significantly present in plants within the quarry areas, raising potential risks to human and animal health. Also, educational initiatives must emphasize the importance of maintaining adequate buffer zones between farmland and industrial operations to prevent heavy metal contamination in agricultural produce. This strategy would mitigate risks of food poisoning and economic losses while contributing to safer food chains. Furthermore, such interventions will reduce human exposure to contaminated plants, thereby enhancing food safety, security, and public health outcomes.

LIMITATIONS OF THE STUDY

Although this study provides critical insights into the relationship between quarrying activities and ecological health, it acknowledges the need for more extensive research. Future studies should investigate:

Quantification of Metal Contamination: Detailed analysis of unexplored metal contents in plants, vegetables, and other food products sourced from quarry-adjacent areas.

Human Health Implications: Longitudinal studies on the effects of chronic exposure to heavy metals through dietary intake, particularly concerning vulnerable populations.

Risk Factor Assessment: Identification and analysis of environmental or physiological factors that increase susceptibility to health issues resulting from metal absorption.

Addressing these gaps will further clarify the broader implications of quarrying on ecological and human health, contributing to the development of long-lasting effective mitigation strategies.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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