GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Pollution effects of quarrying on soil health and nutritional composition of selected vegetables

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GSC Advanced Research and Reviews, 2025, 23(01), 177-185

Publication history: Received on 17 March 2025; revised on 26 April 2025; accepted on 28 April 2025

Article DOI: https://doi.org/10.30574/gscarr.2025.23.1.0126

Abstract

The pollution effects of quarrying on soil health and nutritional composition of Eggplant (*Solanum melongena*) and African Spinach (*Amaranthus hybridus*) were investigated. Soil samples were analyzed for physicochemical indices (Conductivity, pH, TOC, NO_3, PO_4 and Sulphate) and heavy metals (Zn, Cr, Ni, Pb, Cd, Mg, Ca, Mn, and Na) using standard analytical methods. Proximate composition and the level of heavy metals in Eggplant and African Spinach samples were assessed using Atomic Absorption Spectrometry (AAS). Total Organic Carbon (TOC) values in soil ranged from 1.50 ± 1.31% to 3.50 ± 0.49%. Values obtained for soil NO_3 were significantly higher than standards set by WHO and USDA, and ranged from 14.47 ± 0.82mg/kg to 18.86 ± 0.86mg/kg. Analytical results revealed high concentration of Zn and Mn in soil samples from the three quarry sites, when compared to recommended standards. Values for Zn ranged from 14.20 ± 1.21mg/kg to 20.81 ±0.35mg/kg. Proximate analysis of Eggplant and African Spinach cultivated within the quarry environs showed high levels of ash, carbohydrate, protein and dietary fibre. However, the concentration of Cr and Cd in Eggplant exceeded recommended levels. Similarly, Zn, Cr, Mg, Na and Ca in African Spinach also exceeded established standards. Overall, results obtained revealed deterioration of soil quality near the quarries, with significantly high levels of Zn and Mn. These findings suggest that quarrying within the study area has detrimental effects on soil health and suitability of cultivated edible vegetables for human consumption due to possible accumulation of toxic contaminants.

Keywords: Pollution; Quarrying; Soil Health; Nutritional Composition; Vegetables

1. Introduction

The process of extracting gravel, rock or other minerals from the ground is known as quarrying. This process involves various techniques, including drilling, blasting and excavation, to obtain materials like limestone, granite and sand, which are crucial for construction, manufacturing and other industries [1].

According to Nartey *et al.* [2], removal of rock, gravel or other minerals from the earth's surface is important economically, because of their daily use in building of houses, construction of roads and bridges. However, in spite of its huge contribution towards economic development, some adverse effects have been linked to quarry activities [3].

The hazards that follow quarrying are becoming alarming; pollution is highly associated with quarrying activities, especially in a developing country like Nigeria, where regulations guiding mining are not strictly followed [3, 4]. Quarry resources extraction has been documented as a noticeable source of pollution. During the process of quarrying, dusts containing various heavy metals and toxicants are released into the environment [5, 6].

Resultant pollutants from quarrying have been reported to exert detrimental effects on human health, air quality, water quality, and vegetation in the surrounding environment [7]. Deposition of heavy metals and toxicants on the surface of

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plant leaves has been documented [1]. Pollutants being accumulated in the leaves, roots or stem of crops may cause low yield, stunted growth or death of plants [8].

The effects of quarrying on plants should be of concern to all. The process of quarrying has been reported to cause an increase in heavy metal concentration of vegetables and soil [9]. Plants cultivated in areas close to quarry sites take up heavy metals and upon consumption of these plants by man, may result in detrimental effects, because of the accumulation of the heavy metals in the body system [10].

In Ebonyi State, Nigeria, vegetables are widely grown for food and as a means of generating income. *Solanum melongena* (Eggplant) and *Amaranthus hybridus* (African spinach) are important vegetables grown for food at the study location. It is easily noticed that some of these vegetable farms are found closer to quarry sites, thereby causing an increase in the potentials of plants to take up these contaminants, thereby causing detrimental effects on human health.

Researchers have investigated the effects of quarrying activities on plants and soil, however, little published information has been reported for *Solanum melongena* and *Amaranthus hybridus,* especially in Ebonyi State, Nigeria. This study, therefore, evaluates the pollution effects of quarrying on soil health and nutritional composition of bothvegetables in Ebonyi State, Nigeria.

2. Material and methods

2.1. Study Area

The study area (shown in Fig. 1) is located in Ebonyi State, south-eastern Nigeria. Ebonyi State lies approximately within latitudes 5° 40’ and 6° 45’ North of the Equator and longitudes 7°30' and 8°30'East of the Greenwich meridian. The area is characterized primarily by two regimes which are the rainy and the dry seasons. Ebonyi State is bordered by Benue State to the north, Enugu State to the west. Cross River State to the east, and Abia State to the south. Ebonyi State has a population of approximately 3.52 million, with a growth rate of 2.8% since 2022 [11]. The quarrying sites are located at Ngwama in Izzi Local Government Area (LGA), Imama in Afikpo North Local Government Area (LGA) and Ngodo in Afikpo Local Government Area (LGA) of Ebonyi State, Nigeria. The sites have been in operation since at least 1995, when the communities started stone mining for building works and paving [12]. Figure 2 and 3 show harvested stones after blasting and stones crushed into sizes.

2.2. Soil and Vegetable Samples Collection

Soil and vegetable samples were collected in November 2024. Rainy season in the study area is usually from April to October; while the dry season starts from October through to February. Samples of soil were collected at a depth of 0.1 - 0.5m and at different locations within the study area, considering a distance 30 to 50m away from the quarry sites. The vegetables (*Solanum melongena* and *Amaranthus hybridus*) were harvested from locations in close proximity to the quarry sites.

Table 1 Soil and vegetable sample grouping

	Ngwama Quarry	**Imama Quarry**	**Ngodo Quarry**
Soil Sample	NGWs	IMAs	NGOs
Vegetable Sample (*Solanum melongena*)	NGWsm	IMAsm	NGOsm
Vegetable Sample (*Amaranthus hybridus*)	NGWah	IMAah	NGOah

Figure 1 The study area: Ebonyi State, South-Eastern Nigeria

Figure 2 Harvested Stones after Blasting

Figure 3 Stones crushed into granite & sand

2.3. Analytical Methods for Soil Samples

Measurement of soil pH and electric conductivity was carried out using the electrode method [13]. Phosphate in soil was determined by ascorbic acid method [13]. Determination of sulphate in soil was done using turbidity method [14]. For heavy metal analysis, the method of Zhou *et al*. [15] was followed in carrying out sample digestion while Atomic Absorption Spectrophotometer (Perkin-Elmer Analyst 400 model) was used to determine the heavy metal content in digested soil samples. Measurement of nitrate in soil was carried out using cadmium reduction method [14]. Total Nitrogen was determined using Kjeldah method [16]. Rapid oxidation method was used to determine chloride TOC [17].

2.4. Analytical Methods for Vegetables

Determination of the crude fibre, ash, crude fat and moisture content of the vegetables was carried out using the official methods of the Association of Official Analytical Chemists [18, 19]. Acid digestion method was used for the analysis of minerals in the samples of vegetables [20].

2.5. Statistical Analysis

Results in this study are expressed as Mean ± Standard Deviation (SD) while one-way ANOVA was used to test for differences between treatment groups using SPSS version 20. The results were considered significant at p-values of less than 0.05, that is, at 95% confidence level (P=0.05).

3. Results and discussion

3.1. Physicochemical properties of soil from the Quarry areas

Physicochemical properties of soil from Ngwama, Imama and Ngodo quarry sites are presented in Table 2. Results were compared with standard values recommended by the World Health Organization (WHO), United States Department of Agriculture (USDA), the Food & Agriculture Organization (FAO) and the National Environmental Standards and Regulations Enforcement Agency (NESREA). Results showed that electrical conductivity in soil ranged from 192.43 ±5.47 µs/cm to 226.88 ± 15.36µs/cm. These values were below regulatory standards for conductivity in soil. This finding corroborates the work of Igwenagu-Ifeanyi, et al. [9] where the Authors recorded conductivity values from quarry sites to be below regulatory standards. Soil electrical conductivity is important because it indicates the level of dissolved salts and nutrients, influencing soils fertility and sustainability for plant growth, which helps farmers make informed decisions about fertilization, irrigation and soil amendments.

Soil pH values ranged from 6.51 ± 0.10 to 7.11 ± 0.17. TOC values ranged from 1.50 ± 1.31% to 3.50 ± 0.49%. Values obtained for NO_3 in soil ranged from 14.47 ± 0.82 mg/kg to 18.86 ± 0.86 mg/kg, indicating that the values are significantly higher than standards set by WHO [21] and USDA [22].

Table 2 Some physicochemical parameters of soil from the Quarry areas

Parameters	**NGW_s**	**IMA_s**	**NGO_s**	**FAO/WHO [23]; NESREA [24]**
Conductivity (µs/cm)	192.43 ± 5.47^{a}	226.88 ± 15.36^{bc}	221.65 ± 6.95^{bc}	1000
pH	6.51 ± 0.10^{a}	7.11 ± 0.17^{bc}	6.90 ± 0.21^{bc}	6-9
TOC (%)	2.45 ± 0.19^{abc}	1.50 ± 1.31^{ab}	3.50 ± 0.49^{ac}	N.S
NO_3 (mg/kg)	18.86 ± 0.86^{a}	14.47 ± 0.82^{b}	14.47 ± 2.10^{c}	10
PO_4 (mg/kg)	0.49 ± 0.14^{abc}	0.43 ± 0.08^{abc}	0.49 ± 0.02^{abc}	N.S
Sulphate (mg/kg)	13.51 ± 1.21^{a}	11.24 ± 0.35^{b}	21.55 ± 0.97^{c}	500

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at P ≤ 0.05 across the groups. NGW_s - Soil sample from Ngwama quarry; IMA_s - Soil sample from Imama quarry; NGO_s - Soil sample from Ngodo quarry

Table 3 Heavy Metals Concentration (mg/kg) in soil from the Quarry areas

Metals	NGW_s	IMA_s	NGO_s	FAO/WHO [23]; NESREA [24]
Zn (mg/kg)	14.20 ± 1.21^{a}	20.81 ± 0.35^{bc}	18.67 ± 0.97b^{c}	1
Cr (mg/kg)	0.02 ± 1.84a^{bc}	0.02 ± 2.17^{ab}	0.04 ± 1.66^{ac}	0.05
Ni (mg/kg)	0.70 ± 0.0058^{abc}	0.65 ± 0.01^{abc}	0.54 ± 0.01^{abc}	<1
Pb (mg/kg)	0.60 ± 0.28^{abc}	0.41 ± 0.08^{abc}	0.82 ± 0.20^{abc}	1.0
Cd (mg/kg)	0.73 ± 0.08^{a}	0.47 ± 0.33^{b}	0.25 ± 0.11^{c}	1.0
Mg (mg/kg)	36.85 ± 0.07^{ac}	20.79 ± 0.06^{b}	34.24 ± 0.06^{ac}	N.S
Ca (mg/kg)	291.68 ± 10.44^{a}	202.49 ± 0.40^{b}	246.26 ± 1.66^{c}	NS
Mn (mg/kg)	173.23 ± 2.54^{a}	314.30 ± 11.27^{b}	208.73 ± 2.05^{c}	0.2
Na (mg/kg)	43.44 ± 2.25^{a}	61.01 ± 0.06^{b}	52.65 ± 2.26^{c}	N.S

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at $P \leq 0.05$ across the groups. NGW_s - Soil sample from Ngwama quarry; IMA_s - Soil sample from Imama quarry; NGO_s - Soil sample from Ngodo quarry

Table 4 Proximate composition of Eggplant from the Quarry areas

	NGW_{sm}	IMA_{sm}	NGO_{sm}	WHO/EU [21]; USDA [22]
Moisture (%)	61.26 ± 1.09^{a}	54.78 ± 1.71^{bc}	52.13 ± 2.71^{bc}	72.4-95.2
Ash (%)	6.99 ± 0.17^{ac}	8.12 ± 0.26^{b}	7.33 ± 0.59^{ac}	0.2-1.9
Lipid (%)	7.02 ± 0.70^{ab}	6.88 ± 0.23^{ab}	8.08 ± 0.17^{c}	<2g/300g
CHO (%)	7.07 ± 0.08^{ac}	8.24 ± 0.48^{b}	7.04 ± 0.14^{ac}	2.3
Protein (%)	21.15 ± 0.91^{a}	25.18 ± 1.73^{bc}	27.40 ± 1.08^{bc}	0.3-2.0
Crude Fibre (%)	47.42 ± 1.64^{a}	50.66 ± 0.66^{b}	53.58 ± 1.66^{c}	8g/300g

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at $P \leq 0.05$ across the groups. NGW_{sm}- Solanum melongena sample from from Ngwama quarry; IMA_{sm} - Solanum melongena sample from Imama quarry, Imama; NGO_{sm}- Solanum melongena sample from Ngodo quarry

Table 5 Heavy Metals Concentration (mg/kg) in Eggplant from the Quarry areas

Metals	NGW_{sm}	IMA_{sm}	NGO_{sm}	WHO/EU [21]
Zn (mg/kg)	95.66 ± 1.35^{a}	83.07 ± 4.74^{bc}	83.20 ± 5.38^{bc}	99.4
Cr (mg/kg)	6.21 ± 0.35^{ac}	3.91 ± 0.88^{b}	5.24 ± 0.48^{ac}	2.3
Ni (mg/kg)	1.13 ± 0.39^{ac}	0.21 ± 0.02^{b}	1.04 ± 0.14^{ac}	67.9
Pb (mg/kg)	0.09 ± 0.02^{abc}	0.10 ± 0.02^{abc}	0.08 ± 0.04^{abc}	0.3
Cd (mg/kg)	0.07 ± 0.04^{abc}	0.08 ± 0.04^{abc}	0.10 ± 0.05^{abc}	0.2
Mg (mg/kg)	17.94 ± 0.57^{ac}	11.33 ± 0.63^{bc}	14.79 ± 3.81^{abc}	NS
Ca (mg/kg)	20.97 ± 0.20^{a}	18.56 ± 1.13^{bc}	19.14 ± 0.33^{bc}	0.2
Mn (mg/kg)	23.26 ± 0.45^{a}	14.76 ± 0.78^{b}	21.26 ± 0.92^{c}	500
Na (mg/kg)	26.16 ± 0.26^{ab}	25.58 ± 2.13^{ab}	38.83 ± 0.16^{c}	N.S

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at $P \leq 0.05$ across the groups. NGW_{sm} - Solanum melongena sample from Ngwama quarry, ; IMA_{sm} - Solanum melongena sample from Imama quarry, ; NGO_{sm} - Solanum melongena sample from Ngodo quarry

Table 6 Proximate Composition (%) of African Spinach from the Quarry areas

Parameters	NGW_{ah}	IMA_{ah}	NGO_{ah}	WHO/EU [21]; USDA [22]
Moisture	87.97 ± 0.30^{a}	82.38 ± 1.41^{bc}	80.59 ± 0.74^{bc}	72.4-95.2
Ash	22.14 ± 1.51^{ac}	15.98 ± 0.62^{b}	21.29 ± 1.87^{c}	0.2-1.9
Lipid	2.65 ± 0.45^{ab}	2.99 ± 0.12^{ab}	3.99 ± 0.10^{c}	<2g/300g
CHO	4.25 ± 0.29^{ac}	5.88 ± 0.22^{b}	4.19 ± 0.23^{ac}	2.3
Protein	25.50 ± 1.39^{abc}	26.62 ± 1.03^{ab}	23.79 ± 0.84^{ac}	0.3-2.0
Crude Fibre	43.14 ± 0.83^{a}	47.53 ± 0.86^{bc}	46.73 ± 0.97^{bc}	8g/300g

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at P ≤ 0.05 across the groups. NGW_{ah}- Amaranthus hybridus sample from Ngwama quarry; IMA_{ah}- Amaranthus hybridus sample from Imama quarry; NGO_{ah}- Amaranthus hybridus sample from Ngodo quarry

Table 7 Heavy metals concentration (mg/kg) in African Spinach from the Quarry areas

Metals	NGW_{ah}	IMA_{ah}	NGO_{ah}	WHO/EU [21]
Zn (mg/kg)	101.4967 ± 0.93^{abc}	92.54 ± 1.68^{ab}	109.21 ± 7.97^{ac}	99.4
Cr (mg/kg)	6.28 ± 0.51^{ac}	3.72 ± 0.64^{b}	6.15 ± 0.81^{ac}	2.3
Ni (mg/kg)	1.73 ± 0.21^{ab}	1.39 ± 0.33^{abc}	0.97 ± 0.50^{bc}	67.9
Pb (mg/kg)	BDL	BDL	BDL	0.3
Cd (mg/kg)	BDL	BDL	BDL	0.2
Mg (mg/kg)	104.75 ± 4.63^{ac}	81.63 ± 1.69^{b}	102.57 ± 2.36^{ac}	NS
Ca (mg/kg)	23.56 ± 3.46^{abc}	26.98 ± 4.38^{abc}	29.34 ± 0.94^{abc}	0.2
Mn (mg/kg)	39.94 ± 0.48^{a}	33.95 ± 0.41^{b}	45.69 ± 0.61^{c}	500
Na (mg/kg)	24.60 ± 3.84^{abc}	27.76 ± 0.68^{abc}	26.01 ± 4.50^{abc}	N.S

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at P ≤ 0.05 across the groups. NGW_{ah}- Amaranthus hybridus sample from Ngwama quarry; IMA_{ah}-Amaranthus hybridus sample from Imama quarry; NGO_{ah}- Amaranthus hybridus sample from Ngodo quarry

3.2. Heavy metals concentration (mg/kg) in soil from the Quarry areas

Table 3 shows the analytical results for heavy metals in soil from Ngwama, Imama and Ngodo Quarries . Heavy metals analysed are Zn, Cr, Ni, Pb, Cd, Mg, Ca, and Mn. Results reveal high concentration of Zn in soils from the three quarry sites. Values for Zn in soil ranged from 14.20 ± 1.21 mg/kg to 20.81 ±0.35 mg/kg, clearly higher than the recommended standards of WHO, USDA and NESREA. These findings corroborate an earlier research by Igwenagu-Ifeanyi *et al.* [9] where high values were recorded for Zn concentration in quarry soils. Ni values ranged from 0.54 ± 0.01 mg/kg to 0.70 ± 0.01 mg/kg. Values for Pb ranged from 0.41 ±0.08 mg/kg to 0.82 ± 0.20 mg/kg while that of Cd ranged between 0.25 ± 0.11 mg/kg and 0.73 ±0.08 mg/kg. The low levels of Cr, Ni, Pb and Cd may be attributed to soil composition, nature of quarrying activities and the duration of operations [22]. Table 3 further shows the values of Mg to range from 20.79 ± 0.06 mg/kg to 36.85 ± 0.07 mg/kg. Ca values ranged from 202.49 ± 0.40 mg/kg to 291.68 ± 10.44 mg/kg. Ca and Mg are crucial for plants growth, structure, and overall health, impacting nutrient availability and plant processes like photosynthesis and enzyme activity. Mn values ranged from 173.23 ± 2.54 mg/kg to 314.30 ±11.27 mg/kg. Mn values from the three quarrying sites were higher than FAO/WHO [23] and NESREA [24] recommended values.

3.3. Proximate composition (%) of Eggplant from the Quarry areas

The results for moisture, ash, lipid, carbohydrate, protein and crude fibre in *Solanum melongena* (Eggplant) obtained from the Quarry locations are presented in Table 4. Significant decrease was recorded in moisture content values of the eggplant across the three quarrying sites. The moisture content values ranged from 52.13 ± 2.71% to 61.26 ±1.09%. The low moisture content may be attributed to soil compaction (as a result of quarrying activities), dust pollution and soil nutrient deficiencies. These findings are in tandem with the research work of Ogbonna *et al.* [25]. Table 4 shows high values for ash, lipid, carbohydrate and crude fibre in *Solanum melongena* (eggplant) obtained from the three quarrying sites. The ash content values ranged from 6.99 ± 0.17% to 8.12 ± 0.26%. The lipid content values ranged from 6.88 ± 0.23% to 7.02 ± 0.70%. CHO content value ranged from 7.04 ± 0.14% to 8.24 ± 0.48%. Crude fibre content ranged from 47.42 ±1.64% to 53.58 ± 1.66%. The obtained result corroborates the work of Osuocha *et al*. [26] where they noticed increase in proximate composition of vegetables planted in quarry mining effluent discharge soil. These results obtained for dietary fibre could be as a result of development of woody texture in the plant due to enhanced lignin synthesis. Dietary fibre helps to prevent constipation, bowel problems and piles [27]. Conversely, low level of protein was recorded from the quarry sites when compared with the regulatory standards. The protein values ranged from 21.15 ± 0.91% to 27.40 ± 1.08%. Low protein level recorded in this research might be as a result of decreased protein syntheses in the vegetable plant or decreased availability of essential components of amino acids to the site of protein synthesis.

3.4. Heavy metals concentration (mg/kg) in Eggplant from the Quarry areas

Presented in Table 5 are the analytical results for heavy and trace metal namely Zn, Cr, Ni, Pb, Cd, Mg, Ca, Mn and Na in *Solanum melongena* harvested from the quarry areas. Zn values from the three sites ranged from 83.07 ± 4.74 mg/kg to 95.66 ± 1.35 mg/kg, Cr ranged from 3.91 ± 0.88 mg/kg to 6.21 ± 0.35 mg/kg, Ni values ranged from 0.21 ± 0.02 mg/kg to 1.13 ± 0.04mg/kg, Pb ranged from 0.08 ±0.04 mg/kg to 0.09 ±0.02 mg/kg and Cd ranged from 0.07 ± 0.04 mg/kg to 0.10 ±0.05 mg/kg. These results agree with the findings of Ojo et al. [28] who assessed heavy metal pollution in soil from farms in the vicinity of Durumi Quarry site in Mpape, Abuja Nigeria. The low metal levels of the vegetable may be attributed to low pH levels, seasonal variations and soil organic matter. These findings corroborate the research of Osuocha *et al*. [26] where heavy metals were recorded in samples collected from Ishiagu crush rock mining sites in Southeastern Nigeria.

3.5. Proximate composition (%) of African spinach from the Quarry areas

Table 6 shows the proximate Composition (%) of *Amaranthus hybridus* (African spinach) from from the Quarry areas. Values obtained for ash, protein, lipid, CHO, moisture and crude fibre were higher than WHO regulatory standards.

3.6. Heavy metals concentration (mg/kg) in African Spinach from the Quarry areas

Table 7 show some Heavy Metals Concentration in *A. hybridus* (African Spinach) from the Quarry areas. Table 7 reveals high content values of Zn, Cr, Mg, Na and Ca. Values obtained for Mn were below the regulatory values set by WHO. These findings agree with the work of Igwenagu-Ifeanyi *et al*. [9] where high values were high heavy metal levels were recorded in vegetables harvested from quarry locations.

4. Conclusion

The study showed that the surrounding soil of Ngwama, Imama and Ngodo Quarry sites have significantly high levels of Mn, Zn, Cr, Ni, Mg, Ca and Na. Results obtained from this research also indicate heavy metal accumulation in vegetables cultivated within the quarry sites. This suggests that quarrying activities have negative effects on plants and other environmental matrices. Interestingly however, proximate analysis of *Solanum melongena* (Eggplant) and *Amaranthus hybridus* (African Spinach) grown within the quarry environs indicated that the vegetables are good sources of dietary nutrients.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have declared that no competing interests exist.

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