

Assessment of soil physico-chemical properties near limestone mining sites in Eastern Kogi, Nigeria

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Received 25th April 2025; Accepted 20th June 2025

ABSTRACT: The impact of solid mineral mining, like limestone, on the physico-chemical properties of the soil of the study area is a serious problem that needs to be addressed to promote sustainable mining practices and environmental protection. A total of 36 soil samples were collected from six plots using a combination of random and composite sampling methods. The samples were taken at 100-meter intervals along a 400-meter transect extending from the mining site, with additional samples collected 15,000m away along the same path at a depth of 0-15cm. A systematic transect sampling design was adopted for this study, and the collected data were analysed using descriptive statistics. The results of the physicochemical analysis revealed significant alterations in soil properties. Notably, the mean sand content was found to be 80.40%, while the mean silt and clay contents were 12.73% and 6.40%, respectively. The electrical conductivity of the soil ranged from 0.22 to 2.4 ds/m. Furthermore, the study observed an increase in phosphorus, organic carbon, organic matter, total nitrogen, and potassium while pH, sodium, calcium, and magnesium content decreased with an increase in distance from the mining site. These findings suggest that mining activities are negatively impacting soil physico-chemical properties. This can potentially lead to nutrient imbalances and reduced crop yields. The study concluded that there are significant implications for agricultural productivity and food security in the area. Therefore, the study recommended that regular monitoring of soil properties should be conducted in the area to mitigate the adverse effects of limestone mining on the agricultural soils of the environment.

Keywords: Alo, land degradation, low crop yield, nutrient depletion, sustainable mining.

INTRODUCTION

The solid mineral mining industry has historically played a significant role in the socio-economic development of numerous developed and industrialised nations. These countries include Saudi Arabia, Australia, China, Canada, Sweden, Poland, and the United States. The wealth generated from mining activities has contributed to the growth and development of various cities, such as Monterrey in Mexico and Columbia in the United States.

According to Unanaonwi and Amonum(2017), the exploitation of solid minerals can have a positive socio-economic impact. This can be through the provision of natural resources, employment opportunities, revenue, and foreign exchange. Additionally, mining activities can lead to the development of socio-economic infrastructure like roads, schools, and hospitals in host communities. Kogi State boasts an impressive array of solid minerals,

with limestone being one of the most notable. According to Bamidele (2018), the state's mineral wealth is widespread, with every local government area hosting at least one or two types of solid minerals. The diverse range of minerals found in Kogi State includes beryl, cassiterite, tin, coal, columbite, feldspar, garnet, gold, iron ore, kaolin, magnetite, limestone, marble, mica, and several others, underscoring the region's immense geological riches. However, poorly managed mining practices can result in environmental degradation, including soil erosion, land deformation, loss of soil nutrients and micro-organisms (Cruz-Ruiz *et al.*, 2016; Paramasivam and Anbazhagan, 2019; Adranyi *et al.*, 2023). This ultimately affects the sustainability of agriculture in rural areas adjacent to mining environments.

The degradation of soil in mining environments is attributed to the dispersal of particulate matter. This results in the accumulation of various compounds, like calcium (Ca) and magnesium (Mg) in the surrounding soil (Adewole and Adesina, 2011). The physicochemical properties of soil play a crucial role. This is because it determines the mobility and pathways of nutrients to plants (Essandoh *et al.*, 2021), particularly in the context of anthropogenic activities like mining. This has significant implications for global food security, as the physicochemical properties and productivity of soil are intricately linked to food security (Suleiman, 2024). The overall productivity and sustainability of agricultural crop production are highly dependent on the physico-chemical characteristics of the soil. However, solid mineral mining activities can alter these characteristics, thereby affecting both living and non-living components of the ecosystem. This is usually done through the physical and chemical modifications of the soil environment. This, in turn, negatively impacts crop yields in farmlands proximal to mining sites. This is primarily due to the presence of dust particles from minerals such as limestone (Adewole and Adesina, 2011).

Solid mineral mining activities like limestone often involve the clearance of vegetation, which exposes the soil to erosion. This subsequently led to the loss of soil essential nutrients and organic matter. Furthermore, the movement of heavy machinery and the excavation of land to access the desired mineral can lead to various forms of land degradation, such as soil erosion and soil compaction. These disturbances can significantly alter the physico-chemical properties of the soil in the vicinity of the mining environment. This can ultimately affect the overall health and productivity of the soil mineral mining like limestone takes place. There is no doubt that numerous studies have investigated the nature of soil in mining sites within Eastern Kogi State, Nigeria. These studies have examined various aspects of soil contamination and degradation. These include studies like heavy metal pollution (Ameh, 2013; Ekwule *et al.*, 2021), environmental degradation and fatality rates (Akubo *et al.*, 2019), land degradation (Umoru *et al.*, 2019), and seasonal variations

in toxic metal pollution (Ameh *et al.*, 2021). However, despite the extensive research in this area, there is a notable gap in the literature regarding the specific impact of solid mineral mining on the physico-chemical properties of soil in Eastern Kogi State. While previous studies have explored soil quality, this term encompasses a broader range of factors, including biological and ecological processes. However, physico-chemical properties are more narrowly focused on the physical and chemical attributes of the soil. This study aims to address this knowledge gap by assessing soils physico-chemical properties near Limestone mining sites in Eastern Kogi State, to determine the impact of mining on soil health, understanding the effects on ecosystems, and developing effective strategies to mitigate the negative environmental impacts of limestone mining. The study's objective is to evaluate the effects of limestone mining activities on soils physico-chemical properties in Eastern Kogi State.

MATERIALS AND METHODS

Study area

The study was conducted at the Alo mining site, situated in the Ofu Local Government Area of Eastern Kogi State. As shown in Figure 1, the site is located at latitude 6°44'7"N and longitude 7°24'8"E with an altitude of 45 metres. The area is approximately 1.5 kilometres from Itope town, i.e. the major town around the study area. The Alo mining site is a limestone mining area, providing a relevant context for this study. The climate of the area is characterised by distinct rainy (April to October) and dry (November to March) seasons (Abalaka and Tokula, 2018). The mean temperature is 36°C, with maximum temperatures ranging from 29.7 to 35.6°C, while minimum temperatures range from 23.3°C to 25.2°C (Worldclim, 2020). The relative humidity ranges from 36% in the dry season to 80% in the rainy season (Suleiman, 2024). The natural vegetation is predominantly the Guinea savanna. This is characterised by discontinuous canopy, shrubs, and tall trees, giving the area a park-like appearance (Abiola *et al.*, 2015). The vegetation distribution follows a pattern similar to rainfall distribution (Ocholi *et al.*, 2017). Agriculture is the most significant economic activity in the area, with the majority of the population engaged in agrarian pursuits. As a result, the economy and social life of the region revolve around agriculture (Abdulkadir, 1990, and Enefolo, 2021, cited in Ifatimehin *et al.*, 2021).

Sample collection and preparation

Soil samples were collected from the mining site using a transect-based approach, with 400 m transects established and samples collected at 100m intervals at a depth of 0-15 cm. Additional samples were collected up to

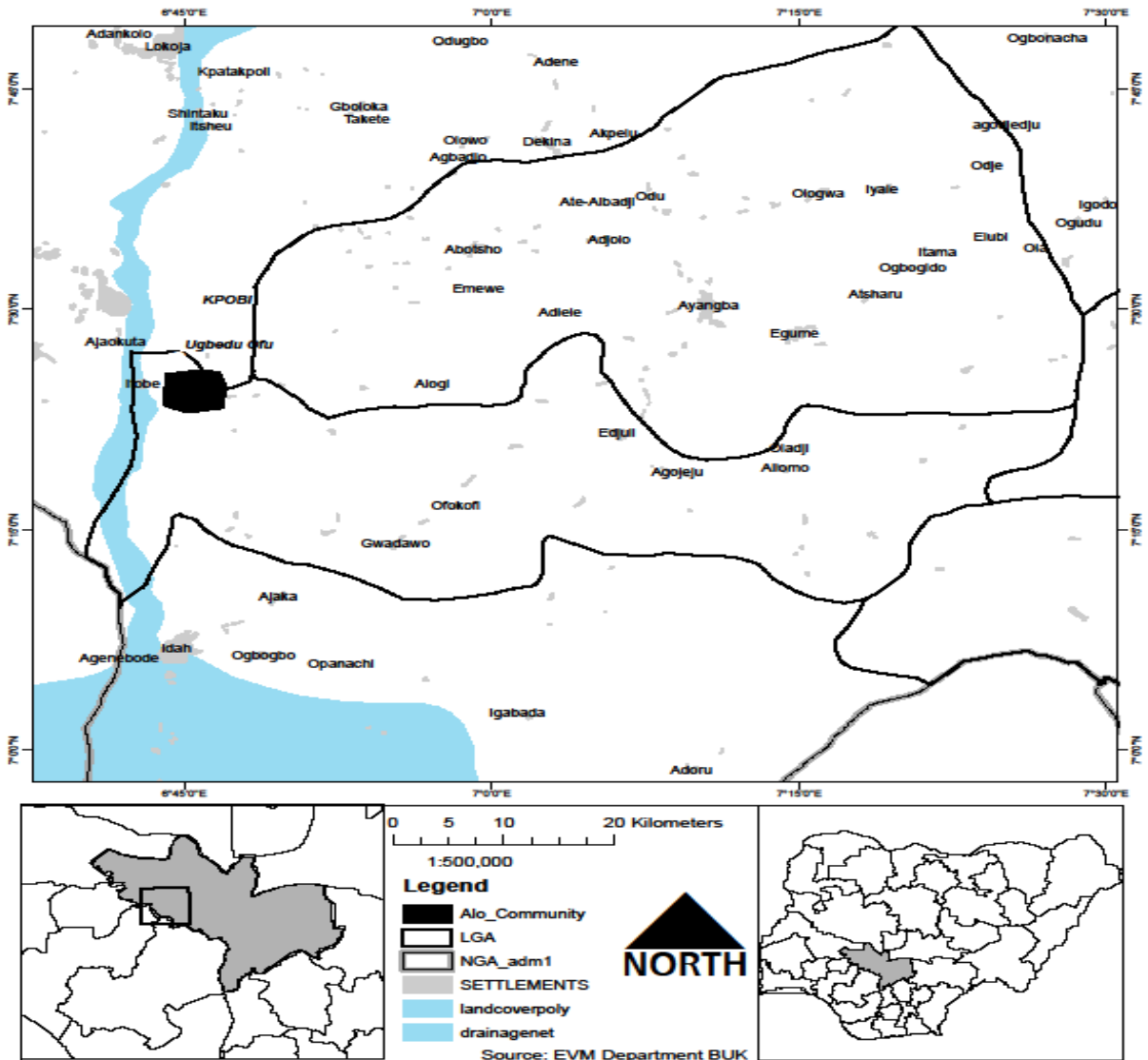


Figure 1. Eastern Kogi State showing the study area (Source: GIS Lab, Department of Environmental Management, BUK).

15,000 m along the same pathway to assess the impact of distance on soil parameters. At each of the six sampling points (0, 100, 200, 300, 400, and 15,000 m), a composite soil sample was created. This was done by randomly collecting and mixing six individual soil samples from 5m² x 5m² established plots along the pathway using a soil auger. This gives one (1) sample from each of the sampled points, where six individual soils were mixed, resulting in a total of six sampled soils. However, this approach yielded a total of 36 composite soil samples. The sampling design combined random and composite sampling to capture representative samples from both mining-impacted and undisturbed areas.

Soil samples were collected at a depth of 0cm-15 cm, representing the plough layer and the zone of maximum rooting depth for most arable crops, where essential

nutrients for plant growth are predominantly concentrated (Ezeaku *et al.*, 2002). The soil samples collected were kept in labelled polythene bags to ensure proper identification. To minimise alterations in soil properties, the samples were promptly transported to the laboratory. Upon arrival, the samples were air-dried, gently crushed with a porcelain pestle and mortar, and sieved through a 2-mm mesh to separate coarse fragments from the fine earth fraction (<2 mm). The fine earth samples were then analysed for the relevant physicochemical parameters.

Laboratory analysis

The particle size distribution of the soil samples was determined using the hydrometer method, as outlined by

Chude *et al.* (2009). The available water holding capacity and moisture content were assessed following the procedures described by Estefan *et al.* (2013). The soil pH was measured electrometrically using a pH meter in 1:1 soil-1M KCl and 1:1 soil-water suspensions, according to McLean (1982). Electrical conductivity was determined using the soil-water suspension method, as described by Estefan *et al.* (2013). Organic matter and organic carbon were analysed using the Walkley-Black wet oxidation method (Nelson & Sommers, 1982). Total nitrogen was determined using the macro Kjeldahl method (Bremner and Mulvaney, 1982), while available phosphorus was assessed using the Bray and Kurtz No. 1 method (Olsen and Sommers, 1982). The exchangeable bases (Ca, Mg, K, and Na) were extracted using the ammonium acetate method, as described by Thomas (1982).

Method of statistical analysis

The data was analysed using Statistical Package for the Social Sciences (SPSS) version 25.0. This was used to determine descriptive statistics like mean and range. The study didn't employ inferential statistics because the primary goal of the study was to describe and summarise the collected data. The laboratory result obtained from the study was equally used to explain how the levels of parameters differ from one sampling point to another. The result was presented in tables to facilitate a better understanding of the study.

RESULTS AND DISCUSSION

Soil physical properties of the mining environment

The particle size distribution, as shown in Table 1, revealed a predominance of sand in the study area, with Sandy soil exhibiting a mean content of 80.40%. Silt content followed next with a mean concentration of 12.73%, while clay content was lowest with 6.40%. A notable trend was observed in Table 3, where sand concentration decreased with distance from the mining area, accompanied by a slight increase in silt and clay content. This finding aligns with previous research by Adewole and Adesina (2011) in Southwestern Nigeria. According to Haritash *et al.* (2007) in a study at the semi-arid Mahendragarh area of India, the decrease in sand content with distance from the mining area may be attributed to the larger particle size of soil in the mining area compared to the surrounding soils. The soil texture in the study site was predominantly sandy loam. The type of soil found in the area may be due to factors like types of parent materials, weathering, etc. This is consistent with the findings of Adewole and Adesina's (2011) study, which reported sandy loam soil texture. However, this result differs from the study of Oladipo *et al.* (2014) in the study

titled ecological impact of mining on soils of south-western Nigeria which reported loamy sand. The sandy loam nature of the soil in this study may be due to limestone mining activities not seriously affecting the soil texture of the environment. This means the soil of the environment can support crop productivity due to its potential for high water holding capacity and high permeability (Iram and Khan, 2018). The current particle size distribution and textural class of the soil remain suitable for crop production. However, prolonged mining activities may alter the soil's composition, potentially shifting it towards a loamy sand texture. This change could compromise the soil's suitability for agricultural purposes. This may ultimately affect the livelihoods of local farmers who depend on the land for farming. Sustained limestone mining operations may thus pose a significant threat to the long-term productivity and sustainability of the soil. This can have potential consequences for food security and the local agricultural economy. The variation in soil texture between this study and other studies like Oladipo *et al.* (2014) in Southwestern may be attributed to factors such as mineral type being mined, mining site age, altitude, and parent rocks (Ahukaemere *et al.*, 2014; Formenky *et al.*, 2018). Existing research confirms that solid mineral mining, like limestone, can significantly alter soil texture. This may affect soil productivity, organic matter content, and structural stability (Ojomah and Joseph, 2017). As presented in Table 3, it reveals a notable pattern is revealed as sand content decreases progressively from 0 m to 15,000 m. This was accompanied by a slight increase in silt and clay content. This pattern suggests that mining activities result in a reduction of silt and clay fractions. This may be due to soil excavation, compaction, and erosion inherent to mining processes (Suleiman, 2024). These changes can have profound implications for soil health and fertility.

The available water holding capacity (AWHC) of the soil, as shown in Table 1, indicated that it ranged between 6.2-12.40%. Notably, the AWHC range in this study differs from those reported by Haritash *et al.* (2007) in a semi-arid region of India (24.5-40.7%). This study revealed an increase in AWHC with distance from the mining sites (Table 3). The available water holding capacity (AWHC) of soils in the study area exhibits a notable trend, as shown in Table 3. The AWHC values demonstrate a consistent increase with distance from the mining site. This suggests that limestone mining activities are significantly impacting the soil's ability to retain water, particularly in areas proximal to the mining site. This finding is consistent with the notion that mining operations can alter soil properties. The low AWHC levels observed in the study site, especially near the mining site, can be attributed to the removal of vegetation, which is a necessary step prior to solid mineral like limestone mining operations (Fomenky *et al.*, 2018). This alteration of the soil's physical properties has far-reaching implications. According to Olayinka *et al.* (2017), low AWHC can negatively affect soil

Table 1. Physical properties of the soil around the mining site.

Soil parameters	Mean	Range
Sand (%)	80.40	76.45-84.40
Silt (%)	12.73	8.67-15.46
Clay (%)	6.40	3.09-9.63
Available Water Holding Capacity (%)	9.03	6.2-12.40
Electrical Conductivity (ds/m)	0.89	0.22-2.4
Textural Class	Sandy Loam	Sandy Loam

Source: Fieldwork, 2024.

characteristics, including void ratio, particle size, and groundwater conditions. The consequences of reduced AWHC in the study area are multifaceted. This may lead to soil problems like soil wetness and porosity being compromised, decreased agricultural productivity and reduced crop yields. This, in turn, can impact the livelihoods of local inhabitants who depend on agriculture for sustenance. Furthermore, the diminished water-holding capacity may disrupt soil ecosystems, as microorganisms struggle to survive in water-scarce environments. These findings underscore the need for careful consideration of the environmental impacts of mining activities like limestone. This is to ensure the implementation of measures to mitigate the adverse effects of mineral mining, like limestone, on soil health and agricultural productivity.

The mean electrical conductivity (EC) as shown in Table 1 ranged from 0.22 ds/m -2.4 ds/m. The EC values in this study were within the range reported by Haritash *et al.* (2007) but lower than those reported by Getnet (2016). The EC content increased with distance from the mining sites. This is consistent with Haritash *et al.* (2007) findings. The mean EC value for this study is within the range considered suitable for agricultural purposes (Iram and Khan, 2018). According to Iram and Khan (2018), the low EC levels in the study sites would not be harmful to germination or injurious to sensitive crops. However, the EC values exceeded the standard range of 0-2 ds/m for agricultural soils recommended by the United States Department of Agriculture (2001), cited in Ajon and Anjembe (2018). The electrical conductivity (EC) levels in the study area reveal an interesting pattern. Notably, EC values at 400m and 15,000m from the mining area surpass the required threshold of 1 ds/m for agricultural soil. This elevated EC at considerable distances from the mining site suggests that factors beyond mining activities may be influencing the soil salinity of the area. A plausible explanation for this phenomenon lies in the inherent characteristics of the soil itself. This could be soil-forming processes or the parent materials from which the soil in these environments is derived. This may be contributing to the high EC levels as observed at 400 m and 15,000 m away from the mining site. This highlights the complex interplay between geological and pedological factors in shaping soil properties.

Soil chemical properties of the mining environment

The mean soil pH value, as shown in Table 2, is 5.54. The soil pH in the study area exhibits a moderately acidic status, as classified by Iram and Khan (2018). This finding aligns with the assertion made by Akinnifesi *et al.* (2005) that African soils tend to be slightly acidic when uncontaminated. This suggests that the soil pH in the study area is consistent with regional trends of most African soils that are uncontaminated. The pH values in this study fell within the range suitable for arable crop farming in Nigeria (Ezeaku, 2012) and favourable for crops like cowpea, groundnut, soybeans, and maize (Chude *et al.*, 2009). The pH values in this study were higher than those reported in some previous studies (Essandoh *et al.*, 2021; Ezeaku, 2012; Oladipo *et al.*, 2014) but lower than those reported by Haritash *et al.* (2007). The variation in pH values between this study and previous research may be attributed to factors like altitude, parent rocks, mining intensity, and rainfall. It is worth noting, as seen in Table 3, that the pH values decrease with distance from the mining sites. This is consistent with the study of Adewole and Adesina's (2011) findings. However, the pattern differed from Haritash *et al.*'s (2007) study, where pH values remained within a range. The pH values in areas around the mining site and 15,000m away are comparable, suggesting that mining activities have had a negligible impact on soil pH levels. This finding implies that the soil pH is likely influenced by inherent geological or pedological factors rather than the mining activities themselves.

The mean phosphorus (P) content, as shown in Table 2, is 17.40%. The available P content in this study exceeded the range reported by Haritash *et al.* (2007) but was lower than values reported by Oladipo *et al.* (2014) and Ezeaku (2012). However, the result was comparable to the mean value reported by Essandoh *et al.* (2021). The laboratory results in Table 3 showed an increase in P content with distance from the mining sites. This finding is consistent with Haritash *et al.* (2007) study in India. The mean P content in this study was below the sufficient agricultural standard recommended by Iram and Khan (2018). However, the mean P content was within the standard range of 8%-20% for soil P content (USDA, 2001, cited in Ajon and Anjembe, 2018). The low P content in some

Table 2. Chemical properties of the soil around the mining site

Soil parameters	Mean	Range
pH	5.54	4.02-6.37
Phosphorus (g/kg)	17.40	39.57-3.82
Organic Carbon (%)	2.60	0.87-6.40
Organic Matter (%)	1.44	0.41-2.37
Total Nitrogen (%)	0.56	0.15-1.20
Sodium (cmol/kg)	0.82	0.02-2.02
Potassium (cmol/kg)	0.41	0.18-0.74
Calcium (cmol/kg)	38.54	16.98-59.08
Magnesium (cmol/kg)	1.9	0.25-3.90

Source: Fieldwork, 2024.

Table 3. Laboratory analysis with distance from the mining site.

Properties	0 m	100 m	200 m	300 m	400 m	15,000 m
Sand (%)	88.24	82	80.21	80.11	77.88	76.92
Silt (%)	14.12	13	14.12	11.67	15.46	13.92
Clay (%)	5.67	9.63	5.67	10.29	6.66	9.63
AWHC (%)	6.20	5	8.30	8.53	10.91	12.40
EC (ds/m)	0.22	0.31	0.43	0.77	1.25	2.40
pH	6.37	6.02	5.91	5.45	4.90	4.02
P (mg/kg)	5.82	8.20	12.24	17.68	20.72	39.57
OC (%)	0.87	1.05	1.73	2.43	2.91	6.40
OM (%)	0.41	0.63	1.56	1.75	1.89	2.40
TN (%)	0.15	0.24	0.47	0.56	0.72	1.20
Na	2.02	1.72	1.05	0.082	0.056	0.015
K	0.18	0.23	0.36	0.41	0.52	0.74
Ca	59.08	47.72	41.26	36.69	29.51	16.98
Mg	3.90	3.42	2.05	1.1	0.61	0.25

Note: AWHC = Water holding capacity, EC = Electrical conductivity, P = Phosphorus, OC = Organic carbon, OM = Organic Matter, TN = Total Nitrogen, Na = Sodium, K = Potassium, Ca²⁺ = Calcium, Mg²⁺=Magnesium.

sampling points, especially between 0m to 400 m, may be a result of mining processes, which usually disturb the soil structure. This leads to reduced availability of phosphorus in the soil around the mining environment. This may limit plant growth, photosynthesis, and fruit formation, potentially affecting crop yields (Olayinka *et al.*, 2017), affect farmers' livelihoods due to their dependency on the soil for farming purposes.

The organic carbon (OC) content, as shown in Table 2, indicated a range of 0.87 - 6.40%. The mean OC content is 2.60% therefore exceeding the standard given by USDA (2001) cited in Ajon and Anjembe (2018). The OC content in this study was higher than the range reported by Haritash *et al.* (2007) but within the range reported by Essandoh *et al.* (2021). However, the mean OC content was lower than the value reported by Oladipo *et al.* (2014) and comparable to the value observed by Adewole and Adesina (2011). The OC content, as shown in Table 3, increased with distance from the mining sites. This is in line with previous studies such as (Haritash *et al.*, 2007; Adewole and Adesina, 2011; Oladipo *et al.*, 2014; Getnet,

2016). However, the OC levels at distances away from the mining sites exceeded the recommended value of 1%-1.8% given by Essandoh *et al.* (2021).

The observed increase in organic carbon with distance from the mining site suggests that mining activities are negatively impacting soil organic carbon levels. This may be as a result of several factors like the removal of vegetation, soil disturbance, erosion, and loss of topsoil around the mining site. These findings support earlier research by Khobragade (2020), which highlighted the detrimental effects of vegetation removal and topsoil loss on soil organic carbon content in humid tropical regions. This consistency underscores the significant impact of limestone mining operations on soil health and fertility.

The organic matter (OM) content, as shown in Table 2, has a range of 0.41-2.37%. The mean OM content in this study site was lower than the standard range of 2-20% for agricultural soil as reported by USDA (2001), cited in Ajon and Anjembe (2018). The mean OM content was higher than the value reported by Unanaonwi and Amonum (2017). However, lower than the values reported by

Ezeaku (2012) in part of Nasarawa State of Nigeria and Haritash *et al.* (2007) in India. The laboratory results, as shown in Table 3, indicate an increase in OM content with distance from the mining sites. This is equally consistent with previous studies like Haritash *et al.* (2007), Adewole and Adesina (2011). The observed increase in organic matter content with distance from the mining site can be attributed to the absence of mining-related disturbances. This is because areas farther away from the mining sites experience less removal of vegetation, soil disturbance, loss of topsoil, and erosion, as well as reduced impact from heavy mining equipment. In contrast, areas close to the mining sites exhibit lower organic matter content. This can have several adverse effects on soil health. According to Ezeaku (2012) and Getnet (2016), reduced organic matter content can increase soil susceptibility to erosion, alter soil pH, and decrease water retention, available water holding capacity, cation exchange capacity, and nutrient availability. These changes can significantly impact soil fertility and overall ecosystem function. This highlights the need for sustainable mining practices that can minimise environmental degradation.

The mean total nitrogen (N) content, as shown in Table 2, is 0.56%. This value falls within the standard of 0.6% for agricultural soils, as reported by the USDA (2001) and cited in Ajon and Anjembe (2018). Comparatively, the mean N content in this study is higher than that reported by Essandoh *et al.* (2021) but similar to values reported by Haritash *et al.* (2007) and Ezeaku (2012). The laboratory results in Table 3 reveal a notable trend in N content with an increase in distance from the mining sites. This finding is consistent with previous studies (Haritash *et al.*, 2007; Adewole and Adesina, 2011; Ezeaku, 2012; Oladipo *et al.*, 2014; Essandoh *et al.*, 2021). The increase in N content away from the mining sites can be attributed to the presence of vegetation, which adds organic matter to the soil, thereby enhancing nitrogen levels. However, the lower nitrogen levels near the mining sites may indicate low organic matter accumulation or increased leaching due to mining-induced soil compaction. It is worth noting that the range of N content in the study area exceeds the recommended range of 0.15%-0.3% for agricultural standards, as reported by Iram and Khan (2018). According to Oladipo *et al.* (2014) the higher N content in some areas may have negative implications for plant growth, development, and metabolic processes.

The mean of sodium (Na^+) content, as shown in Table 2, is 0.82 cmol/kg. The mean Na^+ content in this study exceeded the agricultural standard recommended by Iram and Khan (2018). The range of Na^+ content was within the standard range of 0.1-2 cmol/kg for agricultural soil as reported by USDA (2001) cited in Ajon and Ajembe (2018). The mean Na^+ content in this study was higher than values reported by Haritash *et al.* (2007), Adewole and Adesina (2011), and Ezeaku (2012). However, it was lower than the value reported by Essandoh *et al.* (2021). The laboratory results, as shown in Table 3, indicate a decrease in Na^+

content with distance from the mining sites. This is in line with some studies like Haritash *et al.* (2007) and Adewole and Adesina (2011). However, opposite to what was reported by others like Ezeaku (2012) and Essandoh *et al.* (2021). This decrease may be attributed to the high presence of Na^+ ions around the mining sites, which may be due to mining activities in the area. The abnormal Na^+ levels in some sampling areas, especially areas between 0 – 200 m away from the mining site, may lead to stunted growth, plant death, and negative impacts on vegetative and reproductive phases of plants (Rodriguez Cola *et al.*, 2023). This may ultimately affect the livelihoods of inhabitants engaged in farming activities.

The range of potassium (K^+) content, as shown in Table 2, is 0.18 - 0.74 cmol/kg. The range of K^+ content was within the standard range of 0.2-2 cmol/kg recommended for agricultural soil by USDA (2001), cited in Ajon and Ajembe (2018). The K^+ content in this study was higher than values reported by Essandoh *et al.* (2021), Ezeaku (2012), and Haritash *et al.* (2007). However, it was comparable to the range reported by Adewole and Adesina (2011). The mean K^+ content of this study was within the recommended agricultural standard (Iram and Khan, 2018; Essandoh *et al.*, 2021). The laboratory results shown in Table 3 indicate an increase in K^+ content with distance from the mining sites. This is consistent with the findings of Adewole and Adesina's (2011) in southwestern Nigeria. The finding in this study may be attributed to the low K^+ ion concentration in the soil around mining areas. The current K^+ level is within the threshold limit expected in agricultural soils. However, the continued mining of limestone may disrupt potassium (K^+) levels in the soil, potentially hindering plant growth, protein synthesis, and water balance (Olayinka *et al.*, 2017). Furthermore, abnormal K^+ levels can have far-reaching effects on plant metabolism, including impaired carbohydrate formation and reduced disease resistance. These changes can compromise plant health and productivity, calling for the need for careful consideration of mining's environmental impacts, especially on the soil.

The mean calcium (Ca^{2+}) content, as shown in Table 2, is 38.54 cmol/kg. The mean Ca^{2+} content exceeded the standard range of 2-20 cmol/kg for agricultural soil recommended by USDA (2001) cited in Ajon and Ajembe (2018). The mean Ca^{2+} content in this study was higher than values reported by Essandoh *et al.* (2021), Ezeaku (2012), Oladipo *et al.* (2014), and Unanaonwi and Amonum (2017). However, it was lower than the value reported by Adewole and Adesina (2011). The range of Ca^{2+} content, as shown in Table 2, exceeded the moderate agricultural standard of 5-10 cmol/kg recommended by Essandoh *et al.* (2021). The laboratory results, as shown in Table 3, indicate a decrease in Ca^{2+} content with distance from the mining sites. This is consistent with previous studies such as Adewole and Adesina (2011) and Essandoh *et al.* (2021). The decrease in Ca^{2+} levels near the mining site suggests that mining activities are

influencing calcium concentrations in the surrounding area, particularly in close proximity to the site.

The mean magnesium (Mg^{2+}) content, as shown in Table 2, is 1.9 cmol/kg. The Mg^{2+} content was within the standard range of 0.3-8 cmol/kg for soil Mg^{2+} recommended for agricultural soil by USDA (2001), cited in Ajon and Ajembe (2018). The mean Mg^{2+} content in the study site exceeded the agricultural standard of 0.03-1.0 cmol/kg recommended by Essandoh *et al.* (2021). The mean Mg^{2+} content in this study was lower than values reported by Oladipo *et al.* (2014) and Adewole and Adesina (2011). However, higher than the values reported by Essandoh *et al.* (2021), Ezeaku (2012), and Unanaonwi and Amonum (2017). The laboratory results, as shown in Table 3, indicate a decrease in Mg^{2+} content with distance from the mining sites. This is consistent with the studies of Adewole and Adesina (2011), Ezeaku (2012), Unanaonwi and Amonum (2017) and Essandoh *et al.* (2021). The decrease in Mg^{2+} levels near the mining site suggests that mining activities are influencing Mg^{2+} concentrations in the surrounding area, particularly in close proximity to the site.

In summary, the study highlights the significant impact of limestone mining on soil properties, particularly in close proximity to the mining site of the study area. The changes in soil properties may have implications for soil health, fertility, and agricultural productivity due to alterations in soil composition. The result of the study revealed that soil texture was predominantly sandy loam. This could support crop productivity; however, prolonged mining activities may compromise its suitability for agriculture. The study found that available water holding capacity, organic carbon, organic matter, and total nitrogen, potassium contents increased with distance from the mining site. In contrast, sodium content, calcium, and magnesium decreased away from the mining site. The moderately acidic soil pH and altered nutrient levels suggest that mining activities are negatively impacting soil health and fertility, emphasising the need for sustainable mining practices to minimise environmental degradation and ensure agricultural productivity.

Conclusion and Recommendations

The study has been able to provide up-to-date empirical data on the current state of the physicochemical properties of soil around the Alo limestone mining site in Eastern Kogi State, Nigeria. The study concluded that the impact of solid mineral mining is negatively affecting the physicochemical properties of the soil in the area. This will affect the cultivation of different crops in the area, thus affecting the livelihoods of the dwellers who depend mostly on the soil of the environment for farming purposes. Therefore the study recommended the regular monitoring of the soil around the limestone mining environment due to some unforeseen circumstances in relation to the soil physico-chemical properties of the area, the need for sustainable

mining in the form of adopting technologies for instance in-situ mining that can reduce the environmental impact of limestone mining of the area, the need for the federal or state government to come up with strict limestone mining operation policies of the area to reduce the impact of mining on the soil, and finally the federal or state government should mandate the mining company for the immediate remediation of the area in order to salvage the degraded agricultural lands in the area.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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