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Full Length Research

Comparative analysis of soil physico-chemical properties in solid mineral mining areas of Eastern Kogi State, Nigeria

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ABSTRACT: This study assessed the comparative analysis of the physicochemical properties of soil among solid mineral mining sites in Eastern Kogi State, Nigeria. A total of 144 soil samples were collected from 24 plots using a combination of random and composite sampling methods across the four sites. Samples were collected at 100-meter intervals along a 400-meter transect originating from the mining site. Additional samples were taken 1,500 meters further along the same transect. The collected data was analyzed using statistical methods, including calculation of means, ranges, and Analysis of Variance (ANOVA). The results revealed significant variations in soil parameters relative to proximity to the mining sites. Specifically, most parameters showed an increase with distance from the sites, while pH, sodium, calcium, and magnesium levels decreased. Based on these results, the study concludes that mining operations have a significant impact on soil properties. Consequently, it is recommended that regular soil monitoring be implemented and sustainable land management practices, such as in-situ mining, be adopted to mitigate the adverse effects of mining on soil health. By adopting these measures, the environmental impact of mining can be minimized, and the long-term sustainability of the affected land can be improved.

Keywords: Soil properties, solid mineral mining, soil degradation, sustainable land management.

INTRODUCTION

The global significance of solid mineral mining is multifaceted, driving economic growth, generating income, creating employment opportunities, fostering skill development, and facilitating infrastructure development. This industry has been instrumental in shaping the socio-economic landscape of many developed nations, including Saudi Arabia, Australia, and the United States. However, the environmental consequences of poorly managed mining practices cannot be ignored. Unregulated extraction of minerals like coal and limestone can lead to severe ecological damage, including soil erosion, land deformation, and loss of vital soil nutrients and microorganisms (Ontoyin and Agyemang, 2016; Paramasivam and Anbazhagan, 2019), posing significant threats to national ecosystems (Ahmad *et al*., 2025).

The environmental impact of solid mineral mining largely stems from the release of hazardous materials during extraction and processing. This is due to the prevalent use of surface or open mining methods that generate significant overburdens and mine waste, which are often deposited around mining sites, altering the ecosystem and potentially disrupting the soil's physicochemical properties, particularly when affected by erosion. The devastating effects of solid mineral mining include pit formation, soil erosion, compaction, biodiversity loss, and heavy metal contamination (Ameh, 2013; Zambiri *et al*., 2022; Suleiman, 2024; Ahmad, Rabiu *et al*., 2025).

Soil's physicochemical properties are essential for nutrient mobility and availability to plants (Essandoh *et al.,* 2021), and their preservation is critical for global food security (Suleiman, 2024). Agricultural productivity and sustainability rely heavily on these properties. However, solid mineral mining activities, such as coal and limestone extraction, can alter soil characteristics, impacting both living and non-living ecosystem components through physical and chemical changes. This can lead to reduced crop yields in nearby farmlands, primarily due to the release of mineral dust particles during mining (Adewole and Adesina, 2011).

The global reliance on coal as a primary energy source persists due to its abundance (Rashid *et al.,* 2014) and the high cost of alternative fuels. Similarly, limestone is in high demand for various industrial applications, including cement production, water treatment, soil treatment, and manufacturing of glass, paper, and steel. However, the extraction of these minerals poses significant environmental challenges, particularly in mining areas where local communities depend on the soil for agriculture. Solid mineral mining activities, such as vegetation clearance and heavy machinery use, can lead to soil erosion, nutrient loss, and land degradation, ultimately altering the physicochemical properties of the soil and affecting its health and productivity. (Suleiman, 2024).

There is no doubt that extensive research has been conducted on soil conditions in solid mineral mining sites in Eastern Kogi State, Nigeria, covering topics such as heavy metal pollution (Ameh, 2013; Ekwule *et al.*, 2021), environmental degradation (Akubo *et al*., 2019), land degradation (Umoru *et al*., 2019), soil quality (Ahmad *et al*., 2025), and seasonal variations in toxic metal pollution (Ameh *et al*., 2021). However, a significant knowledge gap exists regarding the comparative assessment of the physicochemical properties of soil among different mining sites in the region. Bridging this gap will provide valuable insights into soil degradation, inform sustainable land management practices, and help minimise environmental impacts, ultimately ensuring long-term ecosystem viability in mining environments.

This study seeks to assess the impact of solid mineral mining on soil health in Eastern Kogi State by comparing the physicochemical properties of soils across different mining sites. By doing so, it aims to provide valuable insights that will inform policymakers and miners about best practices for mitigating the environmental consequences of mining. The findings of this will also contribute to community awareness and education, expand the existing knowledge on soil physicochemical properties in the context of mining, and serve as a foundation for future research on environmental sustainability.

MATERIALS AND METHODS

Study area

As shown in Figure 1, this study focuses on four mining sites in Eastern Kogi State, specifically Odagbo coal site in Ankpa LGA (latitude 07°44' N, longitude 007°23' E), Ajakagwu coal site in Dekina LGA (latitude 07° 03' 6" N, longitude 07°39' 6" E), Omelewu coal site in Olamaboro LGA (latitude 07°43' 6" N, longitude 07°13' 8" E), and Alo limestone site in Ofu LGA (latitude 06°44' 7" N, longitude 07°24' 8" E). Eastern Kogi State comprises nine Local Government Areas. It exhibits a tropical climate with distinct wet and dry seasons. The rainy season typically spans from April to October, while the dry season occurs from November to March (Abalaka and Tokula, 2018). Temperatures in the region are relatively high, with a mean of 36°C and fluctuations between 29.7°C and 35.6°C during the day, and 23.3 to 25.2°C at night (Worldclim, 2020). The area's natural vegetation is Guinea Savannah characterised by a mix of shrubs, tall trees and a discontinuous canopy, giving it a park-like appearance (Abiola et al., 2015). Vegetation distribution is closely tied to rainfall patterns (Ocholi *et al.,* 2017). Agriculture is the backbone of the local economy, with most residents relying on farming for their livelihood. As a result, the region's economy and social life are deeply rooted in agricultural activities (Abdulkadir, 1990; Enefola, 2021, cited in Ifatimehin *et al.*, 2021)

Sample collection and preparation

This study employed a transect-based sampling methodology to collect soil samples from four mining sites (Suleiman, 2017). Within each site, a 400m transect was established, with samples collected at 100m intervals. To assess the impact of distance from the mining site on soil parameters, additional samples were collected up to 1,500m along the same pathway. At each sampling point (100m intervals and 1,500 m), a composite sample was formed by randomly collecting six individual soil samples from 5m^2 x 5m^2 plots using a soil auger. This approach yielded a total of 144 composite soil samples from 24 plots across the four sites, with 36 composite samples per site. The sampling design intentionally targeted both areas directly affected by mining activities and undisturbed areas, utilising a combined random and composite sampling strategy to ensure the collection of representative samples.

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

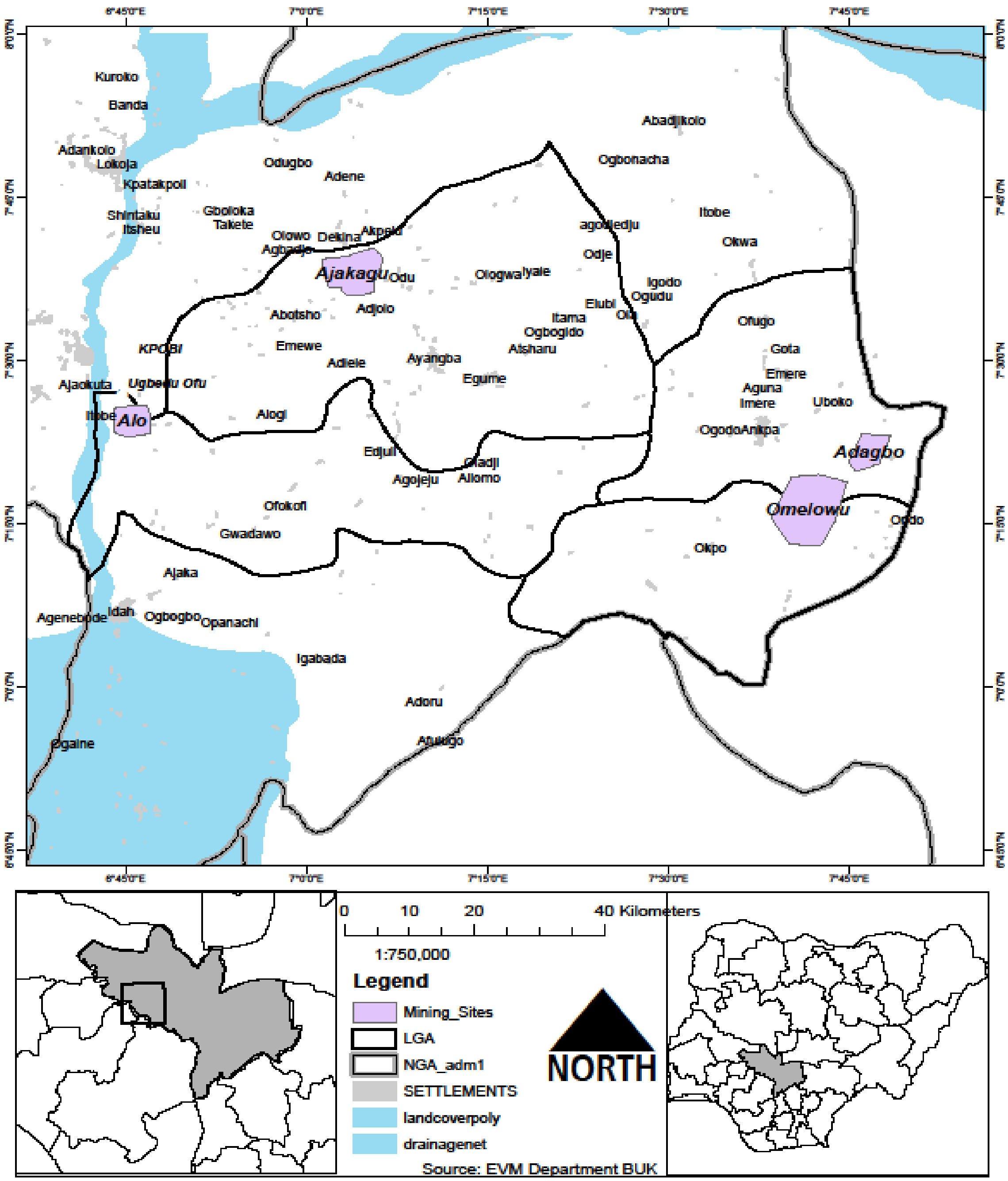

Figure 1. Eastern Kogi State showing the study area (Source: GIS Lab, Department of Environmental Management, BUK 2024).

nutrients are concentrated (Ezeaku et al., 2002). Samples were labelled, stored in polythene bags, and transported to the laboratory to preserve their properties. Upon arrival, they 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. The fine earth samples were then analysed for various physicochemical parameters.

Physicochemical analysis

The physicochemical properties of the soil samples were analysed using various methods. Particle size distribution was determined using the hydrometer method (Chude *et al*., 2009). Available water holding capacity and moisture content were assessed according to Estefan *et al.* (2013). Soil pH was measured electrometrically using a pH meter in both soil-KCl and soil-water suspensions (McLean, 1982). Electrical conductivity was determined using the soil-water suspension method (Estefan *et al*., 2013). Organic matter and organic carbon were analysed using the Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Total nitrogen was determined using the macro Kjeldahl method (Bremner and Mulvaney, 1982), and available phosphorus was assessed using the Bray and Kurtz No. 1 method (Olsen and Sommers, 1982). Exchangeable bases (Ca, Mg, K, and Na) were extracted using the ammonium acetate method (Thomas, 1982).

Statistical analysis

Statistical analysis involved descriptive statistics, such as calculating means and ranges, and one-way analysis of variance (ANOVA)

RESULTS AND DISCUSSION

Soil physical characteristics

The particle size distribution analysis (Table 1) indicated a dominance of sand across the study area, with the Odagbo mining site having the highest sand content (82.75%). The Alo mining site recorded the highest silt content (12.73%). Although the clay content was generally low the Ajakagwu mine site exhibited the highest concentration (7.80%). A notable observation was the decrease in sand content with increasing distance from the mining area, accompanied by slight decreases in silt and clay content. This trend is consistent with previous findings by Adewole and Adesina (2011) in SouthWestern Nigeria. The observed decrease in sand content with distance may be due to the larger particle size of soil in the mining area compared to surrounding soils (Haritash *et al*., 2007). The high sand content across the sites likely reflects the parent material from which the soil was formed. While analysis of variance (Table 3) showed no significant difference in mean particle size distribution among the sites, this indicates that the particle size distribution is relatively consistent or similar across the mining sites.

The study sites predominantly exhibited loamy sand soil texture, except for the Alo mine site, which had a sandy loam texture. This finding is consistent with previous research in Southwestern Nigeria, where similar soil textures were reported by Oladipo *et al*. (2014) for Odagbo, Ajakagwu, and Omelewu mine sites, and by Adewole and Adesina (2011) for the Alo mine site. The loamy sand texture observed in most sites may impact crop productivity due to its low water-holding capacity and high permeability (Iram and Khan, 2018). The variations in soil texture between the Alo site and the other three sites can be attributed to factors such as mineral type, site age, altitude, and parent rocks (Ahukaemere *et al*., 2014; Formenky *et al*., 2018). Mining activities are known to alter soil texture, affecting productivity, organic matter, and structural stability (Ojomah and Joseph, 2017). Notably, the laboratory result (Tables 4, 5, 6 and 7) shows a trend of decreasing sand content and increasing silt and clay content with distance from the mining sites (0 to 1,500 m), suggesting that mining activities due to excavation, compaction, and erosion (Suleiman, 2024), had significant implications for soil health and fertility.

The available water holding capacity (AWHC) of the soil varied significantly across the study sites, with the Alo mining site exhibiting the highest range (6.2%-12.40%) and the Odagbo mining site showing the lowest range (0.78%-3.7%). The AWHC ranges for Ajakagwu and Omelewu mining sites are presented in Table 2. Notably, these ranges differ from those reported by Haritash et al. (2007) in a semi-arid region of India. The analysis of variance (Table 3) showed no significant difference in mean AWHC across the sites. This suggests that the sites may have similar soil properties or characteristics that influence water holding capacity.

Tables 4, 5, 6, and 7 revealed an increase in AWHC with distance from the mining sites, which is in agreement with the study of Haritash (2007) and suggests that increased organic matter away from mining areas may contribute to higher AWHC due to the presence of vegetation. The sites were ranked in descending order of AWHC content across the sites as follows: Alo > Omelewu > Ajakagwu > Odagbo. The low AWHC levels, particularly near the mining sites, can be attributed to vegetation removal (Fomenky *et al*., 2018), which alters soil physical properties with far-reaching implications. Low AWHC can negatively impact soil characteristics (Olayinka *et al*., 2017), compromising soil wetness, porosity, and agricultural productivity, ultimately affecting local inhabitants' livelihoods and soil ecosystems. These findings highlight the need to consider the environmental impacts of mining and implement measures to mitigate adverse effects on soil health and productivity.

The mean electrical conductivity (EC) varies across the study sites, with Odagbo mining site exhibiting the highest value (1.03 ds/m) and Omelewu mining site showing the lowest (0.69 ds/m) as shown in Table I. The EC mean values for Alo and Ajakagwu mining sites were 0.89 ds/m and 0.84 ds/m, respectively. These values are within the range reported by Haritash *et al*. (2007) but lower than those reported by Getnet (2016). Furthermore, the analysis of variance (Table 3) showed no significant difference in mean EC values among the sites, which suggests that the sites may have similar soil properties or characteristics that influence the presence of electrical conductivity of the sites. As shown in Tables 4, 5, 6 and 7, EC values increased with distance from the mining sites, which is consistent with the study of Haritash *et al.* (2007). Most sampling plots had EC values within the standard range for agricultural soils (0-2 ds/m), except in areas 1,500 m away such as Odagbo and Alo mine sites, where

Table 1. Physicochemical properties of soil across the mining sites.

Mining sites	Descriptive statistics	Sand (%)	Silt (%)	Clay (%)	AWHC (%)	EC (ds/m)	TC
Odagbo	Range	78.08-88.00	8.00-13.36	3.00-7.62	0.78-3.7	0.33-2.7	Loamy sand
	Mean	82.75	11.22	5.86	2.16	1.03	
Ajakagwu	Range	75.74-84.50	8.60-14.21	4.30-10.56	4.3-7.60	0.24-2.00	Loamy Sand
	Mean	80.45	11.68	7.80	5.69	0.84	
Omelewu	Range	76.87-82.05	10.11-14.48	3.92-10.65	5.7-9.8	0.11-1.96	Loamy Sand
	Mean	79.93	12.45	7.25	7.24	0.69	
Alo	Range	76.45-84.40	8.67-15.46	3.09-9.63	6.2-12.40	0.22-2.4	Sandy Loam
	Mean	80.40	12.73	6.40	9.03	0.89	

Note: AWHC = Available Water Holding Capacity, EC = Electrical conductivity, TC = Textural Class (Source: Fieldwork, 2024).

Table 2. Chemical properties of soil across the mining sites.

Mining site	Descriptive statistics	pH	P (g/kg)	OC (%)	OM (%)	TN (%)	Na (cmol/kg)	K (cmol/kg)	Ca (cmol/kg)	Mg (cmol/kg)
Odagbo	Range	4.36-6.94	5.65-7.40	0.31-3.70	0.25-2.05	0.18-2.87	0.62-2.46	0.26-0.83	29.62-76.04	5.04-6.4
	Mean	5.90	16.96	1.21	1.34	1.02	1.49	0.50	51.34	2.5
Ajakagwu	Range	4.90-8.10	15.00-6.36	0.65-4.50	0.36-2.46	0.21-2.80	0.11-0.40	0.13-0.25	4.21-65.21	0.5-4.32
	Mean	6.70	9.68	1.7	1.49	0.88	0.22	0.19	36.05	2.07
Omelewu	Range	4.21-7.30	13.67-5.23	0.76-5.60	0.38-2.37	0.15-1.64	0.24-0.52	0.16-0.43	8.51-53.21	0.2-5.1
	Mean	5.72	8.51	2.30	1.47	0.67	0.36	0.29	36.11	2.2
Alo	Range	4.02-6.37	39.57-3.82	0.87-6.40	0.41-2.37	0.15-1.20	0.02-2.02	0.18-0.74	16.98-59.08	0.25-3.90
	Mean	5.54	17.40	2.60	1.44	0.56	0.82	0.41	38.54	1.9

NOTE: P = Phosphorus, OC = Organic carbon, OM = Organic matter, TN = Total nitrogen, Ca = Calcium, K= Potassium, Ca = Calcium, Mg= Magnesium (Source: Fieldwork, 2024).

elevated EC values suggest factors beyond mining activities could influence soil salinity. The inherent characteristics of the soil, such as soil forming processes or parent materials, may contribute to high EC levels at these distances, highlighting the complex interplay between geological and pedological factors in shaping soil properties.

Soil chemical characteristics

The mean soil pH values across the study sites are presented in Table 2, ranging from 5.54 at Alo mining site to 6.70 at the Ajakagwu mining site, with Odagbo and Omelewu mining sites having pH values of 5.9 and 5.72, respectively. The soil pH values indicate moderately acidic conditions at Odagbo, Omelewu, and Alo mining sites (Iram and Khan, 2018), while Ajakagwu mining site had a neutral soil pH suitable for agriculture (Chakraborty, 2015). The pH values are 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*., 2005). Comparing the pH to previous studies, the pH values in this study were higher than in the studies of Essandoh *et al*. (2021) and lower than in the study of Haritash *et al*. (2007). The variation in pH values may be attributed to factors like altitude, parent rocks, mining intensity, and rainfall. Although analysis of variance (Table 3) showed no significant difference in mean pH values among the sites, it indicates that the pH levels are relatively consistent or similar across the sites. The pH values in this study decreased with distance across the various mining sites (Tables 4, 5, 6 and 7),

Table 3. Analysis of variance of the soils parameters across the mining sites.

Parameters	Sum of squares	Df	Mean square	F	Sig.
Between groups	283.704	3	94.568	0.190	0.903
Within groups	164881.320	332	496.630		
Total	165165.023	335			

Source: Fieldwork, 2024.

Table 4. Soil analysis for Odagbo mining site.

Parameters	0 m	100 m	200 m	300 m	400 m	15000 m
Sand (%)	86	85	84	82	81.40	79.08
Silt (%)	8	12	11	12	10.98	13.36
Clay (%)	6	3	5	6	7.62	7.56
AWHC (%)	0.78	1.45	1.50	2.30	3.25	3.70
Ph	6.94	6.65	6.51	5.52	5.30	4.36
EC (dS/m)	0.33	0.44	0.51	0.68	1.50	2.70
P (mg/kg)	7.40	9.51	12.36	15.40	21.45	35.62
OC (%)	0.31	0.38	0.42	0.65	1.80	3.70
OM (%)	0.25	0.67	1.46	1.65	2.00	2.05
TN (%)	0.18	0.26	0.51	0.83	1.46	2.87
Na	2.46	2.01	1.76	1.23	0.83	0.62
K	0.26	0.35	0.48	0.52	0.58	0.83
Ca	76.04	60.52	55.42	47.63	38.82	29.62
Mg	5.04	4.91	2.40	1.62	0.71	0.40

Source: Fieldwork, 2024.

Table 5. Soil analysis for Ajakagwu Mining Site.

Parameters	0 m	100 m	200 m	300 m	400 m	15000 m
Sand (%)	84.30	83.40	81.03	79.56	78.45	75.74
Silt (%)	11.20	8.60	10.37	14.21	12.34	13.70
Clay (%)	4.30	7.87	8.6	6.23	9.21	10.56
AWHC (%)	4.3	4.7	5.23	5.9	6.40	7.60
pH	8.10	7.60	7.20	6.80	5.50	4.9
EC (dS/m)	0.24	0.36	0.47	0.56	1.40	2.00
P (mg/kg)	6.56	6.97	7.48	9.65	12.43	15
OC (%)	0.65	0.81	1.10	1.45	1.91	4.50
OM (%)	0.36	0.86	1.52	1.73	2.03	2.46
TN (%)	0.21	0.27	0.43	0.49	1.05	2.8
Na	0.40	0.28	0.23	0.17	0.14	0.11
K	0.13	0.15	0.17	0.19	0.22	0.25
Ca	65.21	52.11	46.05	38.42	10.32	4.21
Mg	4.32	3.07	2.15	1.40	1.01	0.51

Source: Fieldwork, 2024.

which correlates with the finding of Adewole and Adesina's (2011) findings. The comparable value of pH values in areas around the mining site and 1,500m away suggests that mining activities have had a negligible impact on soil pH levels, implying that inherent geological or pedological factors may be influencing soil pH.

The mean phosphorus (P) content varied across the study sites, as shown in Table 2, with Alo mining site having the highest value (17.40%) and the Omelewu mining site having the lowest (8.51%). The P content for Odagbo and Ajakagwu mining sites was 16.97% and 9.68%, respectively. Compared to previous studies, the available P

Table 6. Laboratory Soil Analysis for Omelewu mining site.

Parameters	0 m	100 m	200 m	300 m	400 m	1500 m
Sand (%)	82.05	81.63	80.48	79.83	78.77	76.87
Silt (%)	14.03	10.33	13.25	10.11	14.48	12.48
Clay (%)	3.92	8.04	6.30	7.84	6.75	10.65
AWHC (%)	5.70	5.90	6.06	7.50	8.50	9.80
pH	7.30	6.90	6.21	5.81	5.60	4.21
EC (dS/m)	0.11	0.28	0.39	0.60	0.82	1.96
P (mg/kg)	5.23	6.05	6.51	8.11	11.51	13.67
OC (%)	0.76	0.92	1.51	2.30	2.60	5.60
OM (%)	0.38	0.71	1.47	1.82	2.06	2.37
TN (%)	0.15	0.23	0.48	0.66	0.87	1.64
Na	0.52	0.43	0.36	0.32	0.28	0.24
K	0.16	0.19	0.25	0.32	0.37	0.43
Ca	53.21	48.24	44.56	36.70	25.42	8.51
Mg	5.10	4.06	2.00	1.30	0.80	0.21

Source: Fieldwork, 2024.

Table 7. Soil analysis for Alo mining site.

Parameters	0 m	100 m	200 m	300 m	400 m	15000 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
pH	6.37	6.02	5.91	5.45	4.90	4.02
EC (dS/m)	0.22	0.31	0.43	0.77	1.25	2.40
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, Ca^{2+} = Calcium = Mg^{2+}=Magnesium (Source: Fieldwork, 2024).

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), although it was comparable to the mean value reported by Essandoh *et al*. (2021). The mean P content across the study sites was below the sufficient agricultural standard recommended by Iram and Khan (2018), but the P content for Odagbo and Alo mining sites fell within the optimal range reported by Essandoh *et al*. (2021). The P content across the study sites was within the standard range of 8%-20% for soil P content recommended by the United States Department of Agriculture (USDA 2001), cited in Ajon and Anjembe (2018). Furthermore, analysis of variance (Table 3) showed no significant difference in the mean of P content among the sites, which suggests that P content is relatively similar across the sites. The results shown in Tables 4, 5, 6 and 7 indicate an increase in P content with distance from the mining sites, which is in agreement with the finding of Haritash *et al*.'s (2007). The low P content in some areas, particularly Ajakagwu and Omelewu mine sites, may be attributed to mining processes that disturb soil structure, reducing P availability and potentially affecting crop yields and farmers' livelihoods.

The organic carbon (OC) content varied across the study sites, as shown in Table 2, with the Alo mining site having the highest range (0.87%-6.40%) and the Odagbo mining site having the lowest range (0.31%-3.70%). The OC content for Ajakagwu and Omelewu mining sites ranged from 0.65%-4.50% and 0.76%-5.60%, respectively. While the mean OC content in Odagbo and Ajakagwu sites was within the standard range for farming (1.0%-2.0%), Omelewu and Alo mining sites exceeded this standard (United States Department of Agriculture, 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). The analysis of variance (Table 3) showed no significant difference in the mean value of OC content among the sites. This suggests that the sites have comparable levels of organic carbon, suggesting similar soil conditions that influence organic carbon storage. Interestingly, the OC content increased with distance from the mining sites as indicated in Tables 4, 5, 6 and 7, and this is consistent with the submission of previous studies of Haritash *et al*. (2007); Adewole and Adesina (2011); Oladipo *et al*. (2014); Getnet (2016). However, OC levels at distances away from the mining sites exceeded the recommended value (Essandoh *et al*., 2021). The observed increase in OC with distance suggests that mining activities negatively impact soil OC levels, likely due to vegetation removal, soil disturbance, and topsoil loss, consistent with earlier research (Salami *et al*., 2002; Agboola, 1982).

The organic matter (OM) content in the soils of the study sites varied, as shown in Table 2, with the Alo mining site having the highest range (0.41%-2.37%) and the Odagbo mining site having the lowest range (0.25%-2.05%). The OM content for Ajakagwu and Omelewu mining sites ranged from 0.36% to 0.36% - 2.46% and 0.38%-2.37%, respectively. The OM content across the study sites was lower than the standard range for agricultural soil (USDA, 2001, cited in Ajon and Anjembe, 2018). The mean OM content was higher than the value reported by Unanaonwi and Amonum (2017) but lower than the values reported by Ezeaku (2012) and Haritash *et al*. (2007). Although analysis of variance (Table 3) showed no significant difference in mean OM content among the sites, this suggests that the sites may share similar characteristics that influence organic matter accumulation and decomposition across the sites. Tables 4, 5, 6 and 7 indicated an increase in OM content with distance from the mining sites, consistent with previous studies of Haritash *et al*. (2007) and Adewole and Adesina (2011). The observed increase in OM content with distance from the mining site can be attributed to reduced mining-related disturbances, such as vegetation removal, soil disturbance, and topsoil loss. This increase in OM content is crucial for maintaining soil health, as reduced OM content could lead to increased soil susceptibility to erosion, altered soil pH, and decreased water retention and nutrient availability (Ezeaku, 2012; Getnet, 2016).

The mean total nitrogen (N) content across the study sites is presented in Table 2, with Odagbo mining site having the highest mean value (1.02%) and the Alo mining site having the lowest (0.56%). The mean N content for Ajakagwu and Omelewu mining sites was 0.88% and 0.67%, respectively. The mean N content was within the standard range for agricultural soil (USDA, 2001, cited in Ajon and Anjembe, 2018), but exceeded the recommended range for agricultural standards (Iram and Khan, 2018). The analysis of variance (Table 3) showed no significant difference in the mean value of N content among the sites. This may suggest that the sites have comparable levels of nitrogen, which may indicate similar management practices. Tables 4, 5, 6 and 7 indicate an increase in N content with distance from the mining sites, which is in agreement with previous studies of Haritash *et al*. (2007), Adewole and Adesina (2011), Ezeaku (2012), Oladipo *et al*. (2014), and Essandoh *et al.* (2021). The increase in N content away from the mining sites may be attributed to vegetation presence, while lower nitrogen levels near the sites may indicate low organic matter accumulation or increased leaching due to mining-induced soil compaction.

The mean sodium (Na^+) content varied across the study sites, as shown in Table 2, with Odagbo mining site having the highest value (1.49 cmol/kg) and Ajakagwu mining site having the lowest (0.22 cmol/kg). The mean Na^+ content for Omelewu and Alo mining sites was 0.36 cmol/kg and 0.82 cmol/kg, respectively. While Ajakagwu and Omelewu mining sites met the recommended agricultural standard (Iram and Khan, 2018), Odagbo and Alo's mining sites exceeded it. The Na^+ content in most sites was within the standard range for agricultural soil (USDA, 2001, cited in Ajon and Ajembe, 2018), except for the Odagbo mine site. The mean Na^+ content was higher than in some previous studies (Haritash *et al*., 2007; Adewole and Adesina, 2011; Ezeaku, 2012) but lower than in the study of Essandoh *et al*. (2021). Further analysis shows that analysis of variance (Table 3) showed no significant difference in the mean value of Na^+ content among the sites. This means the Na^+ content levels are comparable across the sites. The results in Tables 4, 5, 6 and 7 showed a decrease in Na^+ content with distance from the mining sites, consistent with some studies (Haritash *et al.,* 2007; Adewole and Adesina, 2011). The high Na^+ levels near the mining sites may be attributed to mining activities, potentially harming plant growth and affecting farmers' livelihoods.

The potassium (K^+) content varied across the study sites, as shown in Table 2, with Odagbo mining site having the highest range (0.26-0.83 cmol/kg) and Ajakagwu mining site having the lowest range (0.13-0.25 cmol/kg). The mean K^+ content for Omelewu and Alo mining sites was 0.29 cmol/kg and 0.41 cmol/kg, respectively. The mean K^+ content was within the standard range for agricultural soil (USDA, 2001, cited in Ajon and Ajembe, 2018). The K^+ content was higher than in some previous studies (Essandoh et al., 2021; Ezeaku, 2012; Haritash *et al*., 2007) but comparable with the study of Adewole and Adesina (2011). The analysis of variance (Table 3) showed no significant difference in the mean value of K^+ content among the sites, and this suggests that K^+ content is relatively similar across the sites. The results of Tables

4, 5, 6 and 7 showed an increase in K^+ content with distance from the mining sites. This agreed with the finding of Adewole and Adesina's (2011) findings. The mean K^+ content in most sites met the recommended agricultural standard, but continued mining activities may disrupt K^+ levels, potentially harming plant growth, protein synthesis, and water balance. Abnormal K^+ levels can also impair plant metabolism, reducing disease resistance and productivity, highlighting the need for careful consideration of mining's environmental impacts on soil.

The mean calcium (Ca^{2+}) content varied across the study sites, as shown in Table 2, with Odagbo mining site having the highest value (51.34 cmol/kg) and Ajakagwu mining site having the lowest (36.05 cmol/kg). The Ca^{2+} content for Omelewu and Alo mining sites was 36.11 cmol/kg and 38.54 cmol/kg, respectively. The mean Ca^{2+} content exceeded the standard range for agricultural soil (USDA, 2001, cited in Ajon and Ajembe, 2018) and the moderate agricultural standard (Essandoh et al., 2021). The Ca^{2+} content was higher than some previous studies (Essandoh *et al*., 2021; Ezeaku, 2012; Oladipo *et al*., 2014; Unanaonwi & Amonum, 2017) but lower than others (Adewole & Adesina, 2011). Although analysis of variance (Table 3) showed no significant difference in mean value of Ca^{2+} content among the sites, this suggests that there isn't enough evidence to suggest that Ca^{2+} content varies significantly among the sites. The decrease in Ca^{2+} content with distance from the mining sites, as shown in Tables 4, 5, 6, and 7, is in agreement with findings from previous studies (Adewole and Adesina, 2011; Essandoh *et al*., 2021), suggesting that mining activities influence calcium concentrations near the site.

The mean magnesium (Mg^{2+}) content varied across the study sites, as shown in Table 2, with Odagbo mining site having the highest value (2.5 cmol/kg) and Alo mining site having the lowest (1.9 cmol/kg). The mean Mg^{2+} content for Omelewu and Ajakagwu mining sites was 2.2 cmol/kg and 2.07 cmol/kg, respectively. The mean Mg^{2+} content was lower than some previous studies (Oladipo *et al*., 2014; Adewole and Adesina, 2011) but higher than others (Essandoh *et al*., 2021; Ezeaku, 2012; Unanaonwi and Amonum, 2017). The Mg^{2+} content was within the standard range for agricultural soil (USDA, 2001, cited in Ajon and Ajembe, 2018) but exceeded the low agricultural standard (Essandoh *et al*., 2021). The analysis of variance (Table 3) showed no significant difference in the mean value of Mg^{2+} content among the sites, and this suggests that the sites have a comparable level of magnesium content. The results in Tables 4, 5, 6 and 7 showed a decrease in Mg^{2+} content with distance from the mining sites, and this is consistent with the study of Adewole and Adesina (2011). The findings from this study suggested that mining activities are influencing Mg^{2+} concentrations close to the mining site.

Conclusion

Solid mineral mining has a detrimental impact on the soil's physicochemical properties. It also affects crop cultivation and the livelihoods of local farmers who depend on the land. The study reveals that mining operations, including vegetation clearing, excavation, drilling, blasting, and processing, have significantly altered the soil's physicochemical properties. To mitigate this, the study recommends regular soil monitoring, sustainable land management practices like in-situ mining, and stricter mining policies to minimise environmental damage and protect soil health.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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