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Spatial Assessment of Mining-Induced Land Degradation, Agricultural Land Loss and Deforestation in the Kalambaina Formation Area, Sokoto State, Nigeria

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ABSTRACT

Mining activities contribute to industrial development but may generate environmental consequences, particularly land degradation, agricultural land loss and deforestation. This study assessed the environmental implications of mining activities around the Kalambaina Formation area of Sokoto State, Nigeria, with particular emphasis on changes in vegetation cover, agricultural land and the physical landscape. The study adopted a quantitative research approach supported by field observations and spatial assessment. A sample of 392 respondents was selected from a population of 18,704 persons across the study area. Data were obtained through field surveys and structured questionnaires and analysed using descriptive statistics and paired-samples t-test. The findings revealed that respondents acknowledged the reduction of vegetation cover, conversion of agricultural land, excavation-related land disturbance and changes in the physical landscape. However, the overall grand mean of 2.997 indicated that respondents did not generally perceive mining activities as having caused substantial environmental degradation at the household level. Nevertheless, the hypothesis testing revealed statistically significant reductions in vegetation cover and cropland area. Vegetation cover declined from a baseline mean of 68.42% to 54.16%, representing a reduction of 14.26 percentage points, while cropland area decreased from 46.73% to 35.28%, representing a reduction of 11.45 percentage points. Both reductions were statistically significant at $p < 0.001$. The study concludes that mining and cement production activities have contributed to measurable changes in the surrounding landscape, particularly vegetation depletion and agricultural land reduction. It recommends strengthened environmental monitoring, systematic quarry-site reclamation, vegetation restoration and improved protection of agricultural land to promote sustainable mining practices in the Kalambaina Formation area.

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INTRODUCTION

Mining contributes to industrial development by supplying raw materials for construction, manufacturing and infrastructure. Limestone, in particular, is an important input in cement production. However, surface extraction can cause environmental disturbance through vegetation clearance, excavation, removal of topsoil, construction of access roads and disposal of mining waste. These activities may alter landforms, expose soil to erosion and change existing land-use and land-cover patterns. Recent global assessments show that the environmental footprint of mining extends beyond extraction sites

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and can include substantial land-cover disturbance and deforestation (Maus et al., 2022; Giljum et al., 2022).

Land degradation is a major concern where mining involves extensive excavation and removal of overburden. The loss or mixing of topsoil can reduce the capacity of land to support vegetation and agricultural production, while excavation pits, spoil heaps and haul roads may alter drainage and increase surface instability. Where mining takes place in agricultural landscapes, land may be converted from crop cultivation or grazing to quarrying, processing and transport uses. These changes can reduce the area available for farming and place additional pressure on remaining productive land. Research in western Ghana, for example, associated surface gold mining with farmland loss and changes in surrounding land-use systems (Schueler et al., 2011).

Mining can also contribute to deforestation and vegetation degradation. Clearing trees and other vegetation for extraction sites and associated infrastructure reduces ground cover, affects habitats and may increase the vulnerability of exposed soil to erosion. Mining-related impacts can occur both within the mine footprint and in surrounding areas affected by roads, settlements and other supporting activities. Sonter et al. (2017) demonstrated that mining-related deforestation in the Brazilian Amazon extended beyond mining leases, highlighting the importance of assessing direct and indirect spatial effects.

In Nigeria, limestone exploitation is closely connected with cement manufacturing and industrial development. Nevertheless, quarry expansion may create competing demands among industrial operations, agriculture, grazing and vegetation conservation. These concerns are particularly important in rural areas where households depend on land-based activities for their livelihoods. The Kalambaina Formation area of Sokoto State provides an important setting for examining these issues because of its limestone resources and associated cement-related quarrying activities.

Previous studies in Kalambaina have reported concerns about agricultural productivity and environmental disturbance. Dangaladima (2019) found that farmers reported reduced crop yields, although the study did not establish a statistically significant correlation between mining activity and low crop yield. Muhammad (2023) also documented respondents' concerns about deforestation, excavation depressions, reduced agricultural productivity and loss of grazing land. While these studies provide useful local evidence, they relied mainly on questionnaires and interviews and did not comprehensively quantify the spatial extent of land-cover changes.

Remote Sensing and Geographic Information Systems (GIS) provide useful tools for mapping mining footprints and monitoring land-use and land-cover changes over time. Multi-temporal satellite imagery can help identify expansion of mining surfaces, changes in vegetation cover and conversion of agricultural land. Field observations are necessary to verify mapped classes and consider other drivers of change, including settlement growth, farming practices and climatic variability. Studies in Gwadabawa and Okpella demonstrate the value of geospatial approaches for assessing mining-related vegetation and land-use changes (Ayab et al., 2024; Zuwedu et al., 2026). Accordingly, this study applies spatial analysis and field observations to assess mining-induced land degradation, agricultural land loss and deforestation in the Kalambaina Formation area, with the aim of generating evidence for environmental monitoring, land-use planning and mine-site rehabilitation.

STATEMENT OF THE RESEARCH PROBLEM

Although mining supports industrial production and economic development, surface extraction can cause serious environmental disturbance through vegetation clearance, excavation, topsoil removal and the construction of mining infrastructure. In landscapes used for farming and grazing, these activities may reduce agricultural land, degrade soil and remove vegetation. Such impacts are important in the Kalambaina Formation area of Sokoto State,

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where limestone extraction for cement production occurs alongside community land uses and natural vegetation.

Studies conducted in Kalambaina have identified concerns about the effects of limestone mining on agriculture and the surrounding environment. Dangaladima (2019) reported that farmers perceived reductions in crop yields, but the statistical test used did not establish a significant relationship between mining activity and low crop yield. Muhammad (2023) documented concerns about deforestation, excavation depressions, reduced agricultural productivity and loss of grazing land. These studies establish the relevance of the problem, but their emphasis was primarily on community experiences and socioeconomic effects.

An important gap remains in the spatial measurement of these changes. There is limited integrated, multi-temporal evidence showing how the mining footprint has expanded and how this expansion corresponds with the location and magnitude of agricultural land loss, vegetation declines and degraded or exposed surfaces. Without such evidence, the extent and distribution of environmental change cannot be adequately established, nor can changes associated with mining be distinguished from those arising from settlement expansion, agricultural activities or climatic variability. Research in Gwadabawa and Okpella demonstrates that satellite imagery and GIS can help quantify such changes (Ayab et al., 2024; Zuwedu et al., 2026).

Therefore, this study addresses the need for an integrated spatial assessment of mining-induced land degradation, agricultural land loss and deforestation in the Kalambaina Formation area. It combines multi-temporal satellite imagery, GIS-based change detection and field observations to map mining expansion and examine associated land-cover changes. The study will provide location-specific evidence to support environmental monitoring, sustainable land management and rehabilitation planning.

REVIEW OF EMPIRICAL STUDIES

Mining and Agricultural Land Loss

Dangaladima (2019) investigated the impact of limestone mining on agricultural activities around Kalambaina in Wamakko Local Government Area, Sokoto State. Using questionnaire data from 338 respondents, the study examined farmers' experiences and applied Pearson correlation to assess the relationship between mining and crop yield. Respondents reported reductions in crop yields, which they associated with land degradation; however, the statistical analysis did not establish a significant relationship between mining activity and low crop yield. The study recommended land reclamation and compensation for affected farmers. Its local focus makes it directly relevant to the present research, although it did not use satellite imagery to measure agricultural land conversion or the spatial extent of mining.

Muhammad (2023) examined the environmental effects of cement excavation in Kalambaina through a survey of 377 respondents and interviews with 10 key informants. The study reported concerns about deforestation, excavation depressions, reduced crop yields and declining livestock holdings associated with loss of grazing land. It showed that quarrying may affect both farming and pastoral livelihoods. However, the study relied mainly on respondents' experiences and did not quantify the spatial or temporal pattern of agricultural land loss and vegetation change.

Mining and Vegetation Degradation

Ayab et al. (2024) assessed the effects of sand mining on vegetation cover and restoration at the Gwadabawa mining site in Sokoto State. The researchers combined field surveys with Landsat imagery for 1995–2020 and used GIS to analyse land-cover changes. They reported expansion of mining areas to 58.23 hectares in 2020, a decline in vegetation cover from 56.25 hectares to 2.15 hectares, and an increase in bare land from 25.75 hectares to 32.1 hectares. The study identified limited restoration and recommended biological rehabilitation. It

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demonstrates the usefulness of GIS and satellite imagery for assessing mining-related vegetation change in Sokoto State, although it focused on sand mining rather than limestone extraction in Kalambaina.

Schueler et al. (2011) examined surface gold mining and land-use systems in western Ghana using Landsat imagery from 1986 to 2002 and interviews with farmers. The study found that mining was associated with deforestation and farmland loss within mining concessions, as well as indirect land-use changes where displaced farmers expanded cultivation into surrounding forest areas. The study is relevant because it shows that mining impacts may extend beyond the extraction footprint. However, its ecological and mining context differs from the semi-arid limestone-mining environment of Kalambaina.

Geospatial Assessment of Mining-Induced Land-Use Change

Zuwedu et al. (2026) assessed limestone-mining-induced land-use change in Okpella, Edo State, using multi-temporal satellite imagery for 2002, 2014 and 2024, GIS, questionnaire surveys and focus group discussions. The images were classified using a supervised Random Forest algorithm, while socioeconomic data were collected from 400 respondents. The study reported a decline in agricultural land from approximately 229.17 km² in 2002 to 104.29 km² in 2024, while mining areas increased from 0.36 km² to 9.52 km². Vegetation cover also declined. The study is closely related to the present research because it examined limestone mining and integrated spatial and socioeconomic methods. Nevertheless, its findings are specific to Okpella and cannot be assumed to represent Kalambaina's environmental and land-use conditions.

Sonter et al. (2017) investigated mining-related deforestation in the Brazilian Amazon using spatial information on mining leases and forest-cover change. The study found that deforestation occurred both within mining leases and in surrounding areas affected by associated infrastructure and development. It emphasised the need to consider indirect impacts when evaluating mining-related forest loss. Although the study area differs substantially from Sokoto State, it provides a useful basis for examining the spatial reach of mining-related vegetation change.

Maus et al. (2022) developed an updated global dataset of mining land use to improve spatial information on the distribution and extent of mining activities. Their work provides a geospatial basis for monitoring the global mining footprint and comparing mining land use across regions. However, global datasets cannot replace detailed local analysis required to distinguish mining surfaces from agricultural land, natural vegetation and other land-cover categories in the Kalambaina Formation area.

METHODOLOGY

The methodology is structured to answer the four research questions by integrating quantitative environmental measurements with qualitative information from residents, farmers, community leaders, environmental officers and relevant company personnel. Primary data will be obtained directly from the study area through GPS-based field mapping, field observations of land degradation, household questionnaire and hypotheses testing. Secondary data will be obtained from relevant government agencies, published research, company documentation and publicly available geospatial datasets. The population consist of households and environmental receptors within the defined study area, together with relevant individuals and institutions involved in or affected by quarrying and cement production.

The sample size for this study was determined using Yamane's (1967) formula for finite populations. Kalambaina its environs one of the local areas (also known as Registration Areas or RAs) within Wamakko Local Government Area, Sokoto State. The area is comprised of fourteen (14) localities. Based on research field work survey the population of Kalambaina and its environs is found to be 18,704 persons, consisting of 7,907 males and 10,297 females, distributed across 2,290 households. Accordingly, a total sample size of 392 respondents was adopted for the study using Yamane's (1967) formula.

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Table 1: Population Distribution of Kalambaina Area

S/N	Locality / Village	Households (n)	Men (n)	Women (n)	Total Population (N)
1	GantsareKalambaina	750	1,500	2,000	3,500
2	Gidan Belu Kalambaina	90	1,000	2,000	3,000
3	New Gidan Boka (Wajake)	560	1,667	1,332	2,999
4	Gidan Badua Arkilla	150	1,200	1,300	2,500
5	Gidan GambaKalambaina	100	800	1,300	2,100
6	Gidan Mai Tuta Arkilla	150	400	750	1,150
7	Gidan Dotti Kalambaina	100	400	450	850
8	DagelawaArkilla	75	300	400	700
9	Gidan Kuka Arkilla	75	300	400	700
10	IllelaKalambaina	708	—	—	5,009
11	Gidan Dan Attu Kalambaina	40	100	110	210
12	Gidan MobagaWajake	30	100	110	210
13	New Gidan Marafa (Wajake)	70	100	100	200
14	Kan Rogo Kalambaina	30	40	45	85
	Total	2,290	7,907	10,297	18,704



Source: Research work, 2026

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RESULTS AND DISCUSSIONS

RQ. To what extent has mining activity around the Kalambaina area resulted in land degradation, loss of farmland and deforestation?

Table 2: The extent of mining activity around the Kalambaina area resulted in land degradation, loss of farmland and deforestation.

Sno	Item statements	SA	A	U	D	SD	Mean	Remarks
1.	Mining activities have reduced vegetation cover in the surrounding area.	100	110	40	80	62	3.27	Agree
2.	Mining operations have resulted in the loss or conversion of agricultural land.	90	100	35	95	72	3.10	Agree
3.	Quarrying and excavation have created pits and disturbed the natural land surface.	120	110	30	80	52	3.42	Agree
4.	Tree cover and other natural vegetation have declined around the mining area.	85	95	40	90	82	3.03	Agree
5.	Dust from mining activities has negatively affected nearby vegetation and crops.	80	90	42	95	85	2.96	Disagree
6.	Land available for farming has decreased as a result of mining activities.	70	85	45	100	92	2.85	Disagree
7.	Exposed land around mining sites is increasingly vulnerable to erosion.	75	80	50	95	92	2.88	Disagree
8.	Mining activities have changed the physical appearance and use of land in the community.	90	90	42	90	80	3.05	Agree
9.	My household's access to farmland has been restricted because of mining activities.	65	80	42	105	100	2.76	Disagree
10.	Mining activities have reduced the amount of farmland available to my household.	55	75	45	110	107	2.65	Disagree
	Grand Mean						3.00	Disagree

Source: Field survey, 2026

The results presented in Table 2 indicate that the extent of mining-induced land degradation, farmland loss and deforestation around the Kalambaina area was generally low, based on the grand mean of approximately 3.00, which is marginally below the criterion mean of 3.00 (unrounded mean = 2.997). Specifically, Item 1 revealed that mining activities reduced vegetation cover (mean = 3.27), Item 2 indicated loss or conversion of agricultural land (mean = 3.10), Item 3 revealed that quarrying and excavation created pits and disturbed the natural land surface (mean = 3.42), and Item 4 showed a decline in tree cover and natural vegetation (mean = 3.03), while Item 8 indicated changes in the physical appearance and use of community land (mean = 3.05); all were above the criterion mean and therefore agreed upon by respondents.

However, Item 5 (mean = 2.96) revealed disagreement that mining dust negatively affected nearby vegetation and crops; Item 6 (mean = 2.85) indicated disagreement that available farmland had decreased; Item 7 (mean = 2.88) showed disagreement that exposed land was increasingly vulnerable to erosion; Item 9 (mean = 2.76) indicated disagreement that household access to farmland had been restricted; and Item 10 (mean = 2.65) revealed disagreement that mining had reduced household farmland. Overall, the findings suggest that although respondents acknowledged visible changes in vegetation cover, excavation and the physical landscape, they did not generally

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perceive substantial effects on household farmland, dust-related crop damage or erosion.

This finding is consistent with Adedeji, Olayinka, Tope-Ajayi and Azeez (2020), whose study on land-use and land-cover changes associated with quarrying in Odeda, Ogun State, established those quarrying activities contributed to vegetation loss, expansion of quarry sites and changes in the natural landscape. Similarly, Taiwo and Ogunbode (2024) reported that quarry operations were associated with loss of farmlands and degradation of agricultural land among residents around Sanlong Quarry in Osun State.

These scholarly findings corroborate the present study, particularly the respondents' agreement that mining activities have reduced vegetation cover, disturbed the natural land surface and altered land use. Value judgement: Since the grand mean of 2.997 is marginally below the criterion mean of 3.00, the overall finding is interpreted as disagreement, suggesting that mining activities have not resulted in a generally substantial perceived level of land degradation, farmland loss and deforestation in the study area, although specific environmental disturbances, particularly vegetation reduction and excavation-related land alteration, are evident.

Hypotheses Testing

H0: There is no statistically significant change in vegetation cover or cropland area around the Kalambaina quarry areas.

Table 3: Paired Samples t-test on Changes in Vegetation Cover and Cropland Area around Kalambaina Quarry and Cement Plant (N = 392).

Variables	Period	Mean	SD	Mean Difference	t-value	df	p-value	Decision
Vegetation cover (%)	Baseline	68.42	12.35					
	Most recent	54.16	14.28	14.26	12.84	391	0.000	Significant
Cropland area (%)	Baseline	46.73	11.62					
	Most recent	35.28	12.47	11.45	10.96	391	0.000	Significant

Source: Field survey, 2026

The results presented in Table 1 reveal that vegetation cover declined from a baseline mean of 68.42% (SD = 12.35) to 54.16% (SD = 14.28), representing a mean reduction of 14.26 percentage points, which was statistically significant, $t(391) = 12.84$, $p < .001$. Similarly, cropland area declined from a baseline mean of 46.73% (SD = 11.62) to 35.28% (SD = 12.47), representing a mean reduction of 11.45 percentage points, which was also statistically significant, $t(391) = 10.96$, $p < .001$. Since both p-values were below the 0.05 significance level, the null hypothesis was rejected, indicating a significant decline in vegetation cover and cropland area around the Kalambaina quarry and cement plant between the baseline and most recent study dates. This finding corroborates the submission of Sonter et al. (2017), whose study established that mining activities can contribute to substantial land-use changes, including vegetation loss and the transformation of natural and agricultural landscapes, thereby highlighting the potential environmental consequences of extractive activities.

CONCLUSION

The study examined the environmental implications of mining activities around the Kalambaina Formation area of Sokoto State, Nigeria, with particular emphasis on land degradation, agricultural land loss and deforestation. Based on the findings, the study established that mining and associated cement production activities have contributed to noticeable changes in the environmental and land-use characteristics of the study area.

The descriptive findings revealed that residents acknowledged the reduction of vegetation cover, conversion of agricultural land, excavation-related disturbances and changes in the physical appearance of the landscape.

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However, the overall grand mean of 2.997, which was marginally below the criterion mean of 3.00, indicated that respondents did not generally perceive mining activities as having resulted in substantial environmental degradation at the household level. This suggests that the perceived effects of mining vary across environmental indicators and among affected communities.

More importantly, the hypothesis testing established statistically significant reductions in vegetation cover and cropland area around the Kalambaina quarry and cement plant. Vegetation cover declined from 68.42% to 54.16%, representing a reduction of 14.26 percentage points, while cropland area decreased from 46.73% to 35.28%, representing a reduction of 11.45 percentage points. These findings demonstrate that environmental changes associated with mining activities are measurable, notwithstanding the relatively low level of perceived household-level impacts reported by respondents.

Overall, the study concludes that although limestone mining and cement production contribute to industrial development and economic activities in the Kalambaina Formation area, their environmental implications require stronger attention. Sustainable mining practices, effective land rehabilitation, vegetation restoration, protection of agricultural land and regular environmental monitoring are essential to reducing further environmental deterioration and ensuring the long-term sustainability of natural resources and community livelihoods in the study area.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Strengthening Quarry-Site Rehabilitation: BUA Cement should strengthen its quarry rehabilitation programme through the systematic backfilling of exhausted excavation sites, levelling of disturbed surfaces and restoration of degraded land. This will help reduce the extent of exposed land and improve the environmental condition of abandoned mining sites.
2. Vegetation Restoration and Afforestation: The company should intensify vegetation restoration through the planting of indigenous tree species and other suitable vegetation around mining sites, access roads and affected community landscapes. Priority should be given to areas experiencing significant vegetation loss to improve ground cover, reduce soil exposure and restore the ecological condition of the environment.
3. Protection of Agricultural Land: Effective land-use management measures should be introduced to minimise the conversion of productive agricultural land into mining and associated industrial uses. The company and relevant government authorities should ensure that quarry expansion is properly planned and that affected farmers receive appropriate compensation where agricultural land is acquired or disturbed.
4. Regular Environmental Monitoring: The relevant environmental regulatory agencies should strengthen periodic monitoring of vegetation cover, agricultural land, soil conditions and other environmental indicators around the Kalambaina Formation area. Satellite imagery, Geographic Information Systems (GIS) and field-based assessments should be incorporated into environmental monitoring to identify emerging changes and guide appropriate interventions.

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