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Assessment of the impacts of mining activities on vegetation cover and restoration efforts using Geographic Information System (GIS) in the Gwadabawa sand mining site, Sokoto State, Nigeria

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Abstract

Globally, mining is recognized as an inherently economically important process, regrettably, it promotes landscape destruction through deforestation, erosion, pollution, and disruption of soil properties. Addressing these impacts is critical to ensuring environmental health and resilience. This study assesses the impacts of mining activities on vegetation cover and restoration efforts in the Gwadabawa mining sites, Sokoto State, Nigeria. A field survey was conducted to assess the vegetation, the extent of degradation due to mining operations, and the restoration efforts in the area. Landsat images (1995–2020) analyzed using QGIS version 3.18 were used to assess the changes in vegetation for 30 years. Results indicate a significant increase in mining areas (up to 58.23 ha in 2020), a drastic reduction in vegetation cover (from 56.25 ha to 2.15 ha), and an increase in bare soil (from 25.75 ha to 32.1 ha). The presence of natural regenerations and young tree species such as *Combretum nigricans, Piliostigma reticulatum, Sclerocarya birrea, and Adansonia digitata* was evident in the mined-out areas. However, restoration efforts are limited to only arable crop cultivation and fish farming using mining pools as ponds. Given the inadequacy of these measures and the urgent need to combat climate change and land degradation, biological landscape restoration methods are recommended to enhance ecological resilience and biodiversity conservation in the area.

Keywords: Mining; Vegetation Cover; Restoration; Geographical Information System (G.I.S); Gwadabawa

1. Introduction

Sand mining is the extraction of sand, mainly through an open pit from the place of its occurrence. Sand has been used in the construction of roads, dams, schools, health facilities, and houses for thousands of years. Sand mining activities are mostly deemed to be unsustainable not only because they exploit resources, but also because they destroy the environment and society and leave irreversible impacts (Carrere, 2004).

Mining activity is one of the main drivers of deforestation, biodiversity loss, forest degradation, land degradation, land use–land cover (LULC) change, air and water pollution, etc., worldwide (Ranjan et al., 2023). The excavation of mining pits results in significant loss of vegetation in the surrounding areas, reducing biodiversity and ecosystem functions (Giljum et al, 2022). Several studies across the globe, such as Australia, Brazil, China, India, Russia and Ghana revealed remarkable vegetation or forest cover loss due to mining activity (Ranjan et al., 2023)

Nigeria has the world's highest deforestation rate of primary forests according to revised deforestation figures from the Food and Agriculture Organization of the United Nations (FAO, 2005). Between 2000 and 2005, the country lost 55.7 percent of its primary forests – that is, forests with no visible signs of past or present human activity (FAO, 2005); this is due to conversion to non-forest activities such as mining, agriculture, and infrastructural development.

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Mining of gravel and limestone, has created a lot of land degradation problem to the Sokoto state. Agriculture which is the major economic activity of the local populace has been seriously affected due the mining activities. According to Dangaladima (2019), 71% of Farmers living in mining areas in Sokoto state experienced low crop yield on their farms as a result of mining activities carried out and only 23% of farmers are compensated. According to report from various surveys, unregulated human activities in Nigeria, such as illicit sand mining, contribute significantly to environmental devastation, leading to numerous ecological distortions that affect the lives of at least 80 million Nigerians (Dailytrust, 2022).

Remote sensing technology has been widely used to monitor land use/land cover changes and vegetation changes in time and space. It enables a deep understanding of the causes and consequences of the change using multi-date images (Javed and Khan, 2012). Furthermore, GIS allowed for accurate mapping and quantification of the extent of degradation without requiring extensive ground-truthing, which was constrained by the study's limited funding and the challenging terrain. Studies have shown that GIS is a reliable tool for monitoring and assessing land use changes, particularly in areas with resource limitations (Hussain et al., 2020).

Restoration of mining sites is important and has been extensively discussed (Chang et al. 2000; Kuter 2013), resulting in the development and improvement of diverse reclamation scheme. However, occurrences showed that approaches to restoration differ around the world (Adesipo, 2022). Soil reconstruction (backfilling) and revegetation, which are the common reclamation targets of most mining companies (Maiti 2013), cannot cater for the downstream ecological hierarchy and productivity (Jorgensen & Nielsen 2013). While no existing internationally recognized regulations guiding reclamation progress, the few countries with related and monitored national laws have differences in their approaches with identifiable crucial omissions (Adesipo, 2022).

The choice of this research is justified by the urgent need to address the environmental degradation resulting from unchecked mining activities in this remote rural area. The region's bad topography and lack of access to advanced technology for environmental monitoring underscore the importance of adopting cost-effective and widely accessible methods (Ahmed et al., 2019). Geographic Information System (GIS) was selected as the primary tool for this study because it enables comprehensive spatial analysis and visualization of environmental changes using satellite imagery. Given the absence of local historical imagery or advanced recording tools in the study area, GIS provided a practical alternative for analyzing vegetation cover changes over time through freely available satellite data (Ahmed et al., 2019).

2. Methodology

2.1. Study Area

The study area is the Sand mining site in the Gwadabawa/Atakwanyo District in the Gwadabawa Local Government Area of Sokoto State, Nigeria. It lies between 13°22’11” N and 5°13’48” E (Wikipedia). The local government is endowed with natural resources such as Sand, Lateralites, Limestone, and Gypsum. Gwadabawa shares common boundaries with Gada to the North, Illela and Goronyo to the Northeast, Wurno to the Southeast, Kware to the extreme South, and Tangaza to the West (Figure 1).

The area is characterized by a tropical continental climate with fragile ecosystems. Temperatures are high throughout the year while rainfall is low and erratic which barely lasts for more than five months in a year. Average annual rainfall barely exceeds 149mm. The temperature in Gwadabawa varies from 17 °C to 40 °C and is rarely below 14 °C or above 43 °C (Weatherspark, 2019).

The area is also characterized by Sudan Savannah type of vegetation dominated by short grasses interspaced by short woody trees and shrubs. Grasses looks green during the rainy season, but eventually withered and die during the dry season (Davis, 1982).

Mining activities in the area are conducted using traditional, manual methods without the use of heavy machinery such as excavators, bulldozers, or caterpillars. The process follows an open-pit mining approach, where vegetation, including trees and shrubs, is first cleared manually to expose the underlying deposits. Shovels are then employed to dig pits and extract gravel, which is subsequently loaded onto trucks by hand. On average, it takes approximately 20 laborers to fill a single truck.

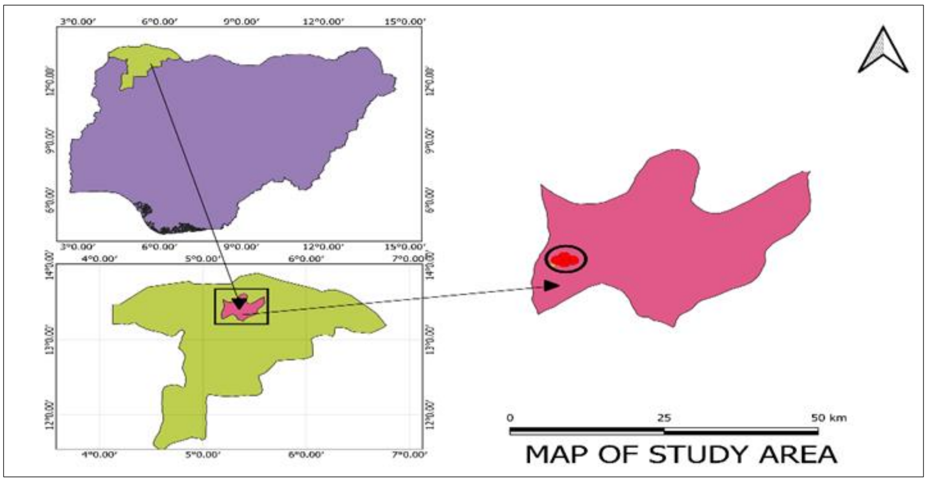

Figure 1 Maps showing the location of Atokonyo district of Gwadabawa L.G.A

2.2. Research Design

The cross-sectional study design was adopted, whereby the study area was visited once during data collection (Kothari, 2004). Electronic (online) data sets and biophysical surveys were used for data collection. Shannon Wiener's diversity index was used to calculate the vegetation (trees, shrubs etc) diversity using the spatial data and ground data (for 2020 analysis).

Table 1 Landsat images used in the analysis of vegetation cover change

Theme	Data Type/Number of Data	Resolution	Time	Source
Landsat 5 TM C1 Level-1	Satellite imagery/27 Data	30m	08/06/1995	https://earthexplorer.usgs.gov
Landsat 7 ETM+ C1 Level-1	Satellite imagery/23 Data	30m	05/01/2000	https://earthexplorer.usgs.gov
Landsat 7 ETM+ C1 Level-1	Satellite imagery/23 Data	30m	20/12/2005	https://earthexplorer.usgs.gov
Landsat 7 ETM+ C1 Level-1	Satellite imagery/23 Data	30m	25/02/2010	https://earthexplorer.usgs.gov
Landsat 8 OIL/TIRS C1 Level-1	Satellite imagery/23 Data	30m	24/12/2015	https://earthexplorer.usgs.gov
Landsat 8 OIL/TIRS C1 Level-1	Satellite imagery/23 Data	30m	21/12/2020	https://earthexplorer.usgs.gov

A reconnaissance survey was conducted to determine the size of the study area and assess the vegetation composition. The area was stratified into two sites namely; mined and un-mined areas. The mined area was selected to carry out measurements on the degraded land and the unmined site was set for tree species identification.

2.3. Image Enhancement

Image enhancement involves mathematical operations that are applied to digital remote sensing input data to improve the visual appearance of an image for better interpretability and analysis (Lillesand *et al.*, 2004). To reinforce the visual interpretability of images, a color composite (Landsat TM bands 3, 4, and 2) Red, Blue, and Green were applied for visual interpretation. However, Band 4, 5, and 3 were used for classification of land cover/use. All image processing was carried out using QGIS software version 3.18.

2.4. Restoration of Degraded Mining Site

The study employed observation and focus group discussion (FGD) methods to assess restoration efforts at the study site. Observations provided direct insights into the current state of vegetation and the effectiveness of implemented restoration activities, while FGDs facilitated the gathering of qualitative data from local stakeholders, including miners and community members, on their perceptions and practices regarding restoration. These methods are widely recognized for their ability to combine empirical field data with socio-environmental insights, making them effective for understanding restoration dynamics in resource-constrained settings (Krueger & Casey, 2015).

2.5. Ground-truthing

A ground-truthing survey was carried out to validate preliminary land cover classifications from satellite imagery using Google Earth and GPS-enabled tools. Field observations, visual image interpretation, and local knowledge provided insights into land use and cover changes, with photographs documenting key features. Data on land cover variations and coordinates were recorded on-site for accuracy.

2.6. Land Use and Vegetation Cover Change Detection and Analysis

In this study, the post-classification change detection method was used to assess vegetation cover and land use changes. Images from different dates were classified and labeled. The area of change was then extracted through the direct comparison of the classification results (Lyoba, 2009). NDVI was used in the detection of land cover changes and Shannon Wiener's diversity index was used in land cover analysis (Kashaigili, 2006).

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

Where, *NIR = band 5 or band 4 (landsat 8 or landsat 7 respectively)*

RED = band 4 or band 3 (landsat 8 or landsat 7 respectively)

Shannon Wiener's diversity index $H1 = -\sum_{i=1}^{s} pi \ln pi$

3. Results and discussion

3.1. Land Cover Changes during the Period of 1995-2020

Using the QGIS and Google earth G.I.S software, temporal and spatial variation of different land cover changes as a result of mining activities and other drivers of land cover changes in Gwadabawa / Atokonyo district were studied. The results of vegetation cover analysis are graphically represented in maps, bar diagram and tables (Table 3, Figures 4, 5, 6 and 7). The result shows the land use maps of the study area for the years 1995, 2000, 2005, 2010, 2015 and 2020 respectively.

The land cover categories delineated in the study area revealed the changes in vegetation cover statistics (in hectare and percentages) that have taken place during the period between 1995 and 2020 are due to expansion of mining activities. Results (Tables 3 and 4 and Figures 3 – 8) indicated variation in land uses classes within the period of 25 years at five years interval (1995, 2000, 2005, 2010, 2015 and 2020).

Table 2 Land cover 1995, 2000, and 2005

Land cover	Land cover 1995 Area (ha)	(%) Coverage	Land cover 2000 Area (ha)	(%) Coverage	Land cover 2005 Area (ha)	(%) Coverage
Bare soil	25.75	31.40244	35.93	43.81818	52.5	64.02439
Vegetation cover	56.25	68.59756	46.07	56.18182	29.34	35.78049
Mining area	0	0	0	0	0.16	0.195122
Total	82	100	82	100	82	100

Table 3 Land cover 2010, 2015 and 2020

Land cover	Land cover 2010 Area (ha)	(%) Coverage	Land cover 2015 Area (ha)	(%) Coverage	Land cover 2020 Area (ha)	(%) Coverage
Bare soil	60	73.17073	73	89.02439	32.1	39.14634
Vegetation cover	21.45	26.15854	6.35	7.743902	2.15	2.621951
Mining area	0.55	0.670732	2.65	3.231707	47.75	58.23171
Total	82	100	82	100	82	100

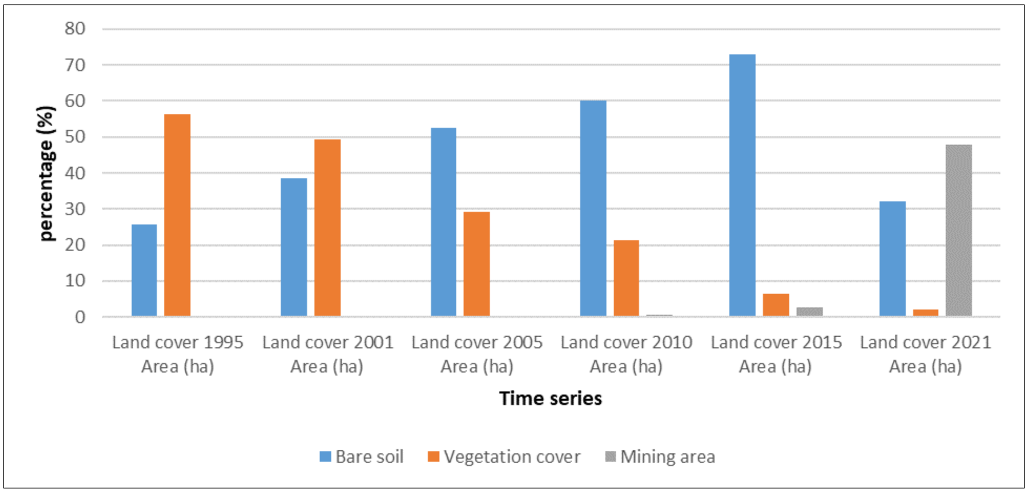

Figure 2 Land cover distribution for Atokonyo district Gwadabawa L.G

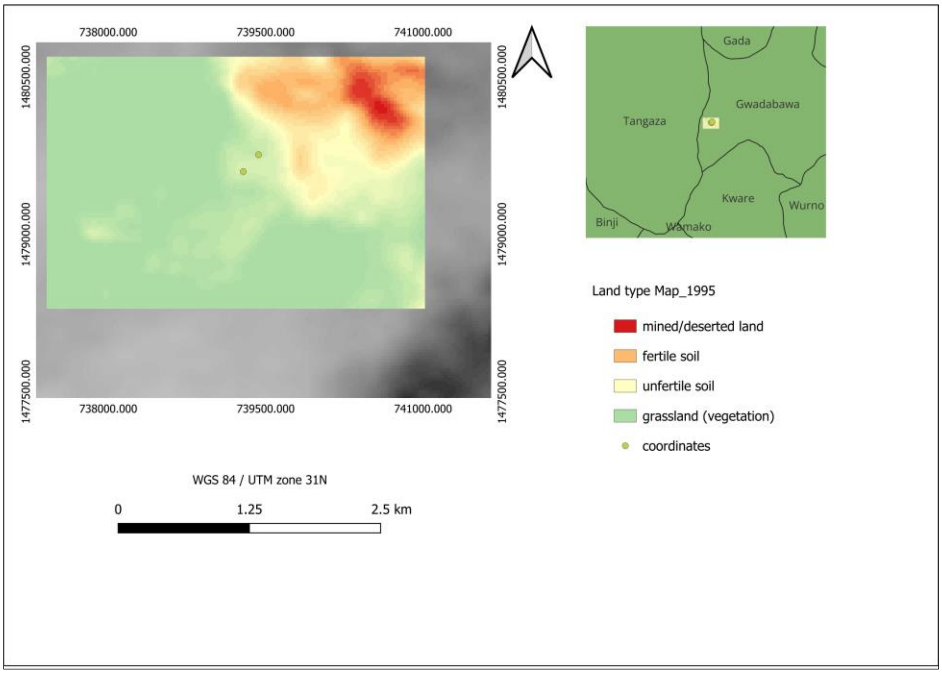

Figure 3 Land use map for Atokonyo district in Gwadabawa L.G 1995

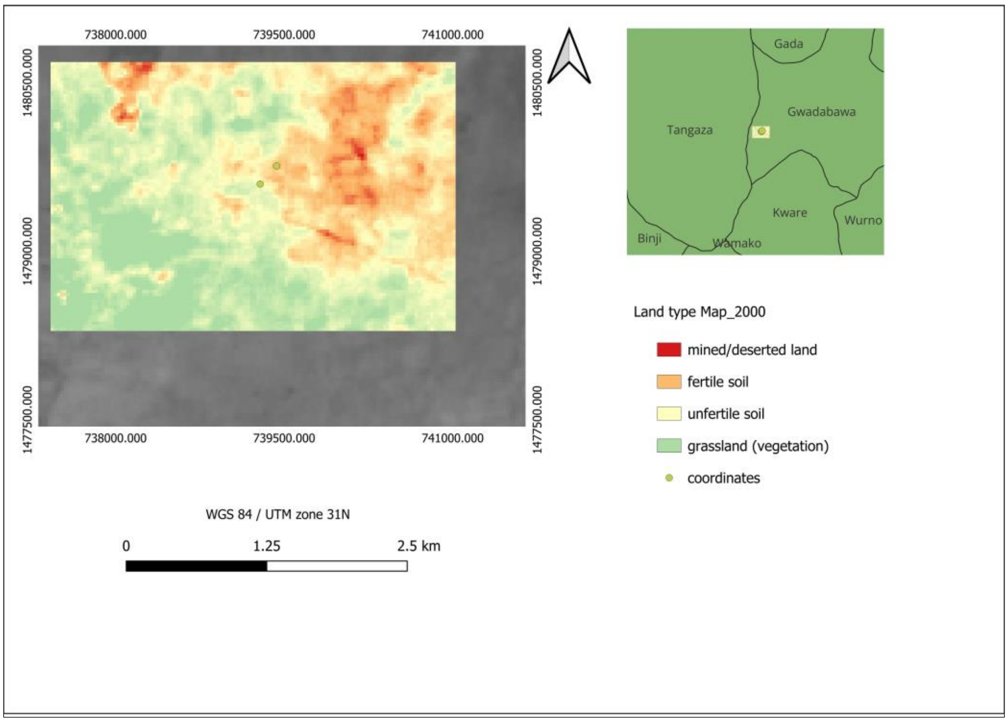

Figure 4 Vegetation cover map for Atokonyo district in Gwadabawa L.G 2000

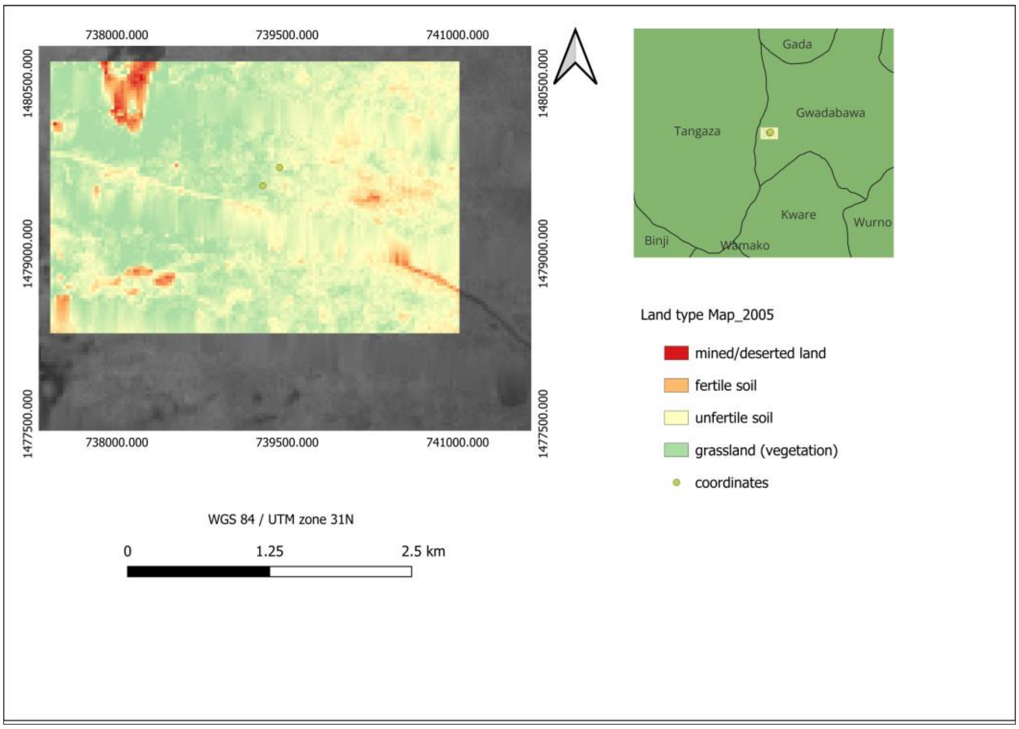

Figure 5 Vegetation cover map for Atokonyo district in Gwadabawa L.G 2005

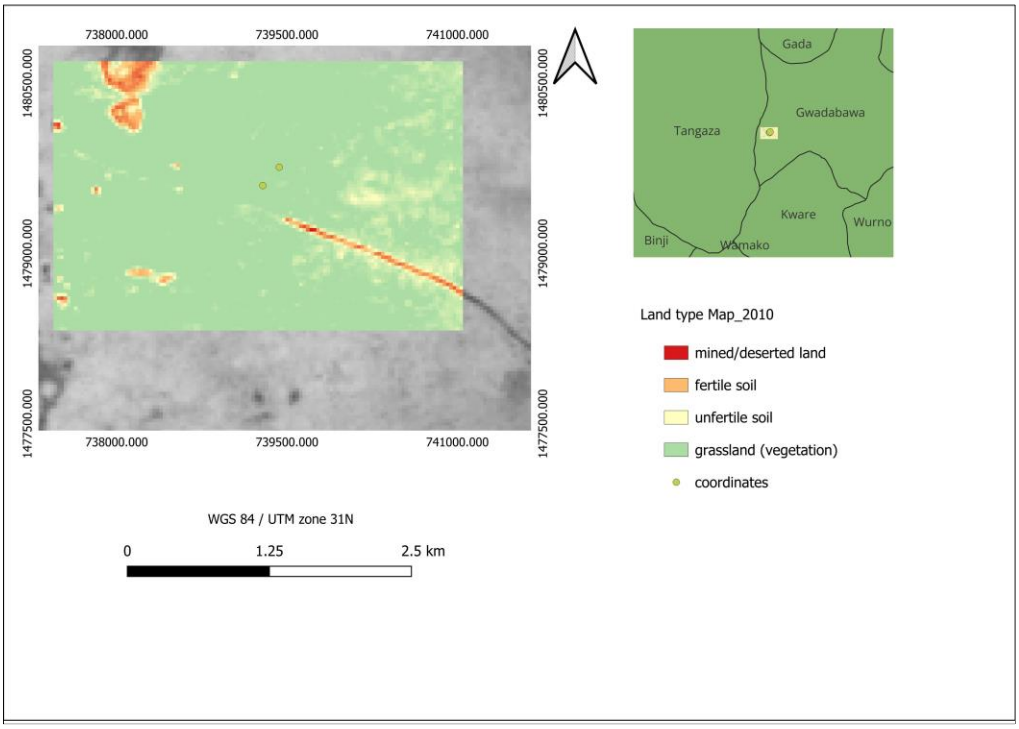

Figure 6 Vegetation cover map for Atokonyo district in Gwadabawa L.G 2010

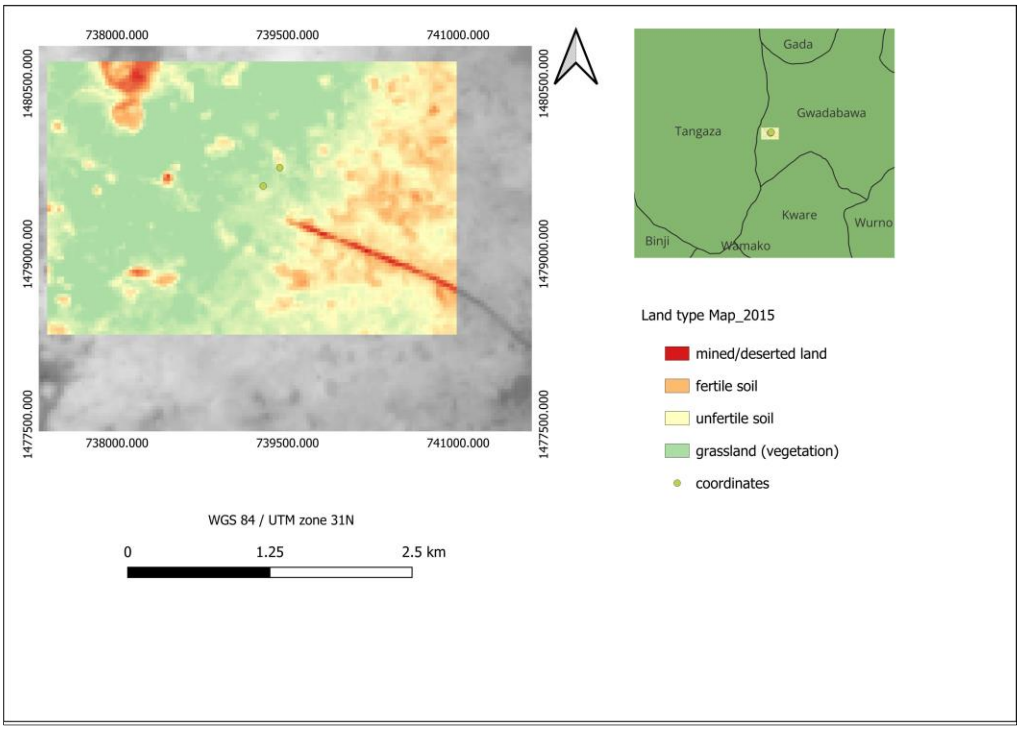

Figure 7 Vegetation cover map for Atokonyo district in Gwadabawa L.G 2015

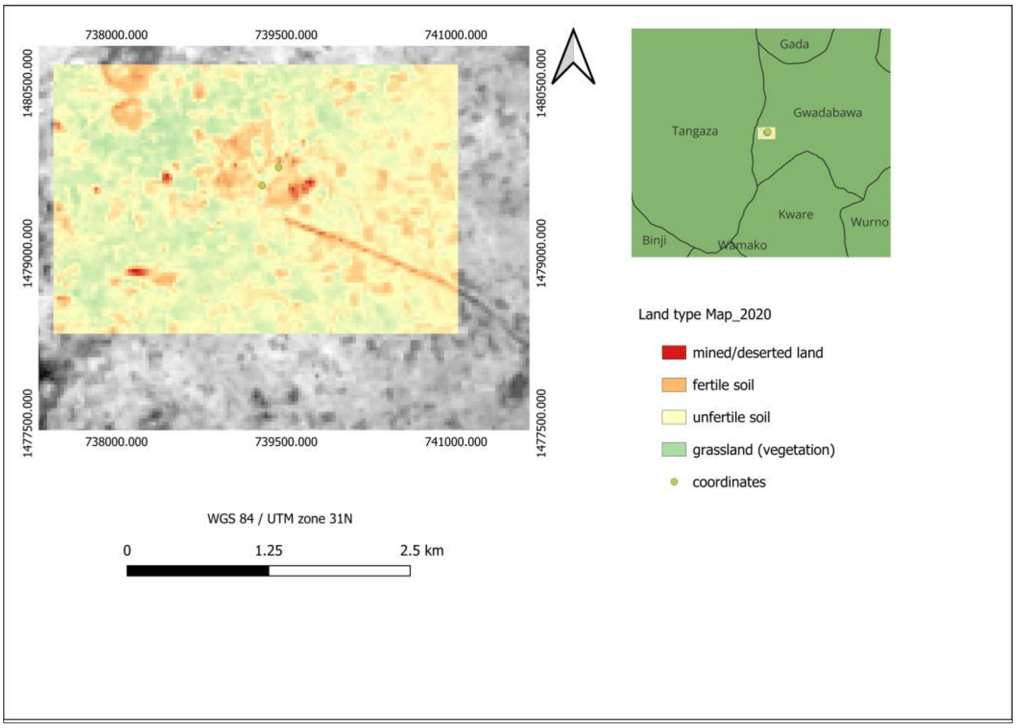

Figure 8 Vegetation cover map for Atokonyo district in Gwadabawa L.G 2020

The study area spans 82 hectares (ha), with significant changes in land use observed over time. In 1995, 25.75 ha were classified as bare land, 56.25 ha were vegetated, and no area was dedicated to mining. Over the years, the extent of bare land consistently increased, leading to a corresponding decrease in vegetation cover. By 2005, bare land had expanded to 52.5 ha, vegetation cover reduced to 29.34 ha, and mining activities began to emerge, occupying 0.16 ha.

The escalation of mining activity, particularly after the operations were taken over by Sufuri Global General Enterprises, significantly altered the land use. By 2020, bare land reduced slightly to 32.1 ha, vegetation cover dramatically diminished to 2.15 ha (representing only 2.62% of the area), and mining operations expanded to occupy 47.75 ha.

From 1995 to 2000, vegetation cover underwent a sharp decline due to deforestation, as native vegetation was cleared for non-vegetative land uses, including farming, construction, and residential development. Vegetation cover decreased from 56.25 ha to 29.35 ha (-52.2%) between 1995 and 2005 and further declined to 2.15 ha by 2020 (-96.2%). This trend highlights the substantial impact of human activities, particularly mining, on vegetation cover.

Between 2015 and 2020, mining activities surged, causing a drastic transformation of the land use. Mined land increased from 2.65 ha in 2015 to 47.75 ha (58.23%) in 2020. These changes illustrate how mining accelerated the depletion of vegetation cover. The findings align with studies such as Garry (2001), which reported that even small-scale gold mining can significantly reduce vegetation cover and ecosystem services due to slow forest recovery. Similarly, Sarma (2005) documented the adverse effects of extensive mining on vegetation and habitat conditions.

Despite the ongoing deforestation, mitigation measures such as replanting initiatives have shown some success in restoring parts of the degraded land. The rate of vegetation cover decrease slowed from 70.4% between 2010 and 2015 (21.45 ha to 6.35 ha) to 66.1% between 2015 and 2020 (6.35 ha to 2.15 ha). These changes reflect the positive impact of restoration efforts, including the planting of trees, shrubs and arable crops to replace lost vegetative cover. Similar results were observed in sandpits and stone quarries, where succession towards reed or drylands was achieved, as noted by Řehounková and Prach (2006) and Trnková et al. (2010). Vegetation establishment in dry regions has also been documented in Czech Republic quarries, as highlighted by Novák and Prach (2003). The listed tree species below which were believed to habituate the area are almost completely endangered because only few stands of the species were observed.

3.2. Flora Composition of the Study Area

The unmined portions of the study area were utilized to identify the floral composition, documented during ground-truthing exercises and confirmed through Focus Group Discussions (FGDs) with local respondents. Several species listed in Table 4 were not observed in the field but were verified by respondents as previously present.

Notably, species such as *Hyphaene thebaica* (Doum palm) and *Adansonia digitata* (Baobab tree) are now endangered due to mining activities. Most of the documented species are native to the region, except for *Azadirachta indica* (Neem tree), which was introduced as a windbreak along the roads. This distinction underscores the ecological importance of native species and the severe disruption caused by mining activities.

Species marked with the suffix (F) in Table 4 were observed during ground-truthing, while unmarked species were confirmed through FGDs but not found in the field. These findings highlight the urgency of conserving the remaining flora and rehabilitating the ecosystem to restore biodiversity.

Table 4 List of tree/shrubs species that habituate the study area

S/N	Name	Botanical name	Local name	Family	Nativity
1	Combretum (F)	*Combretum nigricans*	Taramniya	Combretaceae	Native
2	Camel's foot (F)	*Philiostigma reticulatum*	Kalgo	Fabaceae	Native
3	Tamarind	*Tamarindus indica*	Tsamiya	Fabaceae	Native
4	Baobab (F)	*Adansonia digitata*	Kuka	Malvaceae	Native
5	Doum palm (F)	*Hyphaene thebaica*	Goriba	Arecaceae	Native
6	Jujube (F)	*Ziziphus mauritiana*	Magarya	Ziziphaceae	Native
7	Christ thorn	*Ziziphus spina-christi*	Kurna	Ziziphaceae	Native
8	Desert date	*Balenite aegyptiaca*	Aduwa	Zygophyllaceae	Native
9	Marula (F)	*Sclerocarya birrea*	Danya/Nunu	Anarcadiaceae	Native
10	Acacia (F)	*Faidherbia albida*	Gawo	Fabaceae	Native
11	Neem (F)	*Azadirachta indica*	Darbejiya	Meliaceae	Exotic
12	Apple of Sodom (F)	*Calotropis procera*	Tumfafiya	Apocynaceae	Native

3.3. Restoration Efforts

From field observations, ground-truthing, and information gathered from respondents during the Focus Group Discussions (FGD), several mitigation and restoration methods have been initiated on the degraded lands. While these measures are not yet sufficient to fully restore the affected areas, they have significantly contributed to reducing the adverse impacts of mining. This positive trend is evident in the mapped changes observed between 2015 and 2021.

The following are the measures the inhabitants put in place to mitigate the degraded lands.

- **Planting of Arable Crops:** By leveraging the proximity of the soil to groundwater, degraded areas have been transformed into arable farms. This has enabled the practice of irrigation farming, with crops such as rice (*Oryza sativa*), tomato (*Lycopersicum esculentum*), and soybean (*Glycine max*) being cultivated. These crops not only provide food security but also improve soil fertility and nutrient retention, reducing erosion and further degradation.
- **Establishment of Ponds:** Local ponds have been constructed within the degraded areas to serve as reservoirs for storing water. These ponds help maintain soil moisture, support irrigation during dry periods, and contribute to creating a stable microenvironment for the surrounding vegetation.

3.4. Recommendations

While the current mitigation measures implemented by the inhabitants are commendable, additional restoration actions can further enhance the sustainability of the degraded lands and restore their ecological balance. These actions include:

- **Land Reclamation:** Land reclamation involves raising the elevation of a waterbed or low-lying area to restore usability. Due to the mining activities, the affected area has become a low-lying land, making reclamation an essential approach. The most effective method is the earth movement technique, which involves transporting soil from other areas to fill the degraded site. This measure is crucial for restoring the land's usability and reducing the adverse impacts of mining.
- **Regeneration:** The study area once had a composition of tree stands before mining activities destroyed the stands. Regenerating the land by replanting native trees will help mitigate environmental impacts, restore the ecosystem, and provide fruitful results. Tree planting will also aid in restoring lost biodiversity, such as birds and other wildlife, by recreating suitable habitats.
- **Environmental Impact Assessment (EIA) Certification:** For areas yet to be mined, conducting Environmental Impact Assessments (EIA) and obtaining certifications before commencing mining activities is vital. This ensures that mining is carried out sustainably, with minimal impact on the surrounding environment.
- **Livestock Management:** Introducing livestock rearing can contribute to restoring soil nutrients. Animals feeding on plant roughages will naturally fertilize the soil through their defecation, gradually enriching the land. This approach can complement other restoration measures by promoting a self-sustaining nutrient cycle.
- **Engaging Professional Miners:** To ensure sustainable mining practices, professional miners should be employed for future mining activities. Their expertise can minimize environmental degradation, ensure adherence to best practices, and integrate restoration processes during and after mining operations.

Gwadabawa Local government authorities should institute management practices in the villages adjacent to the mining area, such as planting of local trees species. This could be a solution to overcome the present problems of land degradation which will save the future sources of energy and ecosystem resilient in the study area.

Negative effects of mining activities include depletion and destruction of finite resources like vegetation cover and forest structure. The activities jeopardize the natural resources needed for future generation. Therefore, it is important to evaluate how the community will be affected after closing the mines and to propose the ways of ensuring their sustainability after mine closure. Also, the law enforcement to the project owner should be adhered to.

4. Conclusion

This study demonstrates the significant impact of mining activities on vegetation cover in Gwadabawa, Sokoto State, highlighting a drastic reduction in vegetation and an increase mining areas over a 25-year period. While some restoration efforts, such as planting arable crops and establishing ponds, have shown positive outcomes, they remain insufficient to address the ecological degradation comprehensively. The findings underscore the urgent need for sustainable land reclamation, environmental impact assessments, and reforestation efforts to restore biodiversity and mitigate further damage. By adopting these recommendations, this study provides a pathway to improving ecosystem resilience, benefiting both local communities and broader environmental sustainability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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