

TEMPORAL PATTERNS OF LAND USE CHANGE IN MAIGANGA: A CASE STUDY OF THE EFFECTS OF MINING AND RECLAMATION

*¹Nsor Charles Ayuk, ²Nya John Usim, ³Isyaku Abdulkadir, ⁴Francis Wada, ⁵Binta Abubakar, ⁴Amina Haruna Aliyu

¹Department of Zoology and Wildlife Ecology, Gombe State University, Gombe, Nigeria

²Lafarge Africa

³Department of Geography and Environmental Management, Gombe State University, Gombe, Nigeria

⁴Department of Biological Science, Gombe State University, Gombe, Nigeria

⁵Department of Science Laboratory Technology, Federal Polytechnic Kaltungo, Nigeria

*Corresponding Author Email Address: charlesnsor@yahoo.co.uk

ABSTRACT

Land resources, ecological processes, and human development activities make land-use patterns a key indicator of environmental sustainability. The Maiganga coal field in Gombe State, Nigeria, presents a distinctive landscape where active mining has occurred alongside progressive reclamation efforts by Lafarge Africa and Ashaka Cement. This study assessed land-use and land-cover (LULC) changes in the area before mining, during extraction, and following reclamation over twenty years. The classification of multi-temporal Landsat imagery identified five major LULC categories: vegetation, farmland, bare surface, settlement, and water bodies. The results show distinct LULC transitions across the study timeline. Vegetation cover increased substantially after 2010, coinciding with ongoing reclamation and restoration practices. Farmland exhibited variable patterns influenced by shifting agricultural activity and land accessibility. Bare surfaces initially expanded during intensive mining but later decreased as stabilization and re-vegetation progressed. Water bodies increased mainly due to the formation of artificial ponds within excavated pits, reflecting hydrological adjustments in the mined terrain. Settlement areas exhibited irregular patterns of change, reflecting broader land-use dynamics and classification variability. Overall, the findings demonstrate that reclamation activities in Maiganga have contributed to measurable ecological recovery, although evidence of mining disturbance remains visible. The study highlights the importance of continuous monitoring and adaptive management to support long-term environmental sustainability in mining-affected landscapes.

Keywords: Land-use-change, Maiganga, coal, reclamation, vegetation

INTRODUCTION

Landscapes worldwide are rapidly transforming as human activities expand (Gbadegesin *et al.*, 2023). The accelerated pace of anthropogenic pressure has altered natural environments so extensively that truly pristine habitats are now rare, occurring mostly within inaccessible regions of protected areas and core conservation zones. Human influence reaches almost every corner of the biosphere, reshaping ecological processes, modifying species composition, and changing the structure and function of terrestrial ecosystems. This global trend of landscape alteration is closely linked to agricultural expansion (World Bank, 2017), infrastructural development, resource extraction, and the growing demands of urban and industrial societies (Ceballos *et al.*, 2015; Steffen *et al.*, 2015; Gbadegesin *et al.*, 2023).

Among the drivers of land-use and land-cover dynamics, mineral extraction stands out as one of the most transformative (Eneanya, 2022). Mining activities, particularly open-pit extraction, cause extensive disturbances by clearing vegetation, displacing soil, creating artificial landforms, altering hydrological pathways, and reshaping the landscape's physical characteristics. In Nigeria, coal extraction has played a central role in energy production and industrial development. Its contribution to national growth and socioeconomic advancement is well recognized, given coal's substantial share in global electricity generation and its historical importance during industrialization phases in many countries. However, the environmental consequences of coal mining are significant and often long-lasting, affecting soil quality, biodiversity, water resources, and land stability (Abatcha *et al.*, 2024).

The Maiganga coal field in Gombe State is a notable example of a landscape undergoing intensive resource extraction alongside deliberate restoration efforts. Since mining began in 2005, the area, formerly a mosaic of rural settlements, grazing patches, farmlands, and savanna vegetation, has experienced marked changes in land cover (Abatcha *et al.*, 2024). Mining operations led to increased bare surfaces and altered vegetation patterns, accompanied by the formation of artificial ponds within mined-out pits. Although mining introduces considerable landscape disturbance, the mining company (Lafarge Africa) operating in the area has adopted progressive reclamation strategies for mined land concurrently with ongoing extraction. These reclamation initiatives typically involve back-filling excavated pits, stabilizing slopes, and promoting natural regrowth through re-vegetation and tree planting. This aligns with the global expectation to ameliorate and reduce the negative impacts of extractive activities, mining and allied industries.

Land-use and land-cover changes (LULCC) have played a pivotal role in shaping the dynamic relationship between humans and their environment. According to Kayet and Pathak (2015), these changes reflect the intensity of anthropogenic influence on ecosystems. Moreover, LULCC has become an essential tool for managing natural resources and detecting environmental anomalies (Kumar & Agrawal, 2019). Globally, land-use and land-cover change (LULC) has been linked to biodiversity loss, ecological fragmentation, and degradation of ecosystem services. Similar concerns apply to the Maiganga landscape, where shifts in vegetation, farmland distribution, settlement expansion and relocation, the emergence of water bodies, and bare ground reflect

complex interactions among mining activity, natural regeneration, and human land-use practices. The area's ecological context, characterized by dry savanna vegetation, seasonal climatic patterns, and socio-economic dependence on farming and grazing, makes it particularly sensitive to environmental disturbances (Abdulsalam *et al.*, 2016; Oruonye *et al.*, 2016; Nsor *et al.*, 2022).

Given the dynamic nature of the Maiganga coal field, a systematic assessment of LULC changes evaluates the extent of landscape transformation and the effectiveness of reclamation practices. Remote sensing provides an essential tool for monitoring such changes across time and space, enabling multi-year comparisons of land-cover patterns and quantification of transitions among different classes. By examining changes in vegetation cover, farmland distribution, bare surfaces, water bodies, and settlements, it becomes possible to understand both the direct impacts of mining (Garai & Narayana, 2018) and the restorative processes. The impact of restorative processes such as artificial wetlands created to treat and release heavy metal-laden water from active mined areas through a sedimentation pond was recently investigated using water bird species diversity and abundance as indicators of the implications of mining on biodiversity and environmental sustainability (Nsor *et al.*, 2022; Nsor & Nya, 2025).

This study therefore aims to detect, quantify, and interpret land-use and land-cover changes in the Maiganga mining area over twenty years, beginning from the onset of mining operations in 2005 to 2025. The assessment highlights both the disturbances created by mining and the degree of ecological recovery achieved through progressive reclamation interventions. Through this analysis, the study contributes to broader discussions on sustainable mining, landscape restoration, and environmental management in resource-dependent regions.

MATERIALS AND METHODS

Study Area

The Maiganga coal mine is situated within Maiganga community, Akko Local Government Area (LGA), Gombe State, Nigeria. The mine coordinates are approximately 9°99'07.22"N latitude and 11°15'31.42"E longitude, while the community itself lies at 9°58'48.8"N and 11°08'57.9"E. The Maiganga community covers approximately 48.165 km² (2,129.47 acres). The village is located 8 km from the Gombe –Yola Road, west of Kumo town, within the dry Savannah ecological zone dominated by grasses, shrubs, and thorn-scrub interspersed with sparse tree species such as *Pakia biglobosa*, *Tamarindus indica*, *Balanites aegyptiaca*, *Butyrospermum paradoxa*, *Azelia africana*, and *Adansonia digitata* (Abdulsalam *et al.*, 2016; Nsor *et al.*, 2022). The area has a tropical continental climate with distinct wet and dry seasons, annual rainfall ranging from 850 –1000 mm, and a rainy season lasting approximately five to six months (Oruonye *et al.*, 2016). The region supports diverse vertebrate species, including squirrels, bats, giant monitor lizards, venomous snakes, and small rodents.

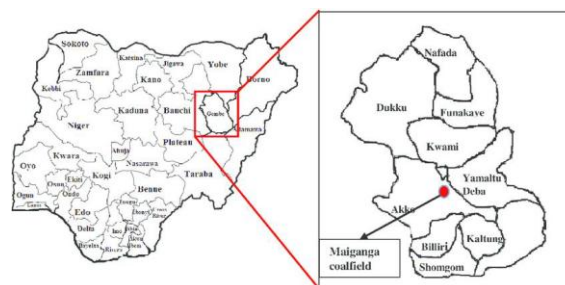


Figure 1: Map of Akko LGA showing Maiganga coal mine field. (Source Koko *et al.*, 2016)

Data Collection

Multi-temporal satellite imagery from the Landsat series was employed to assess land use and land cover (LULC) changes in the Maiganga coal mining area. Landsat imagery was chosen due to its long-term archive availability, 30-meter spatial resolution, and spectral bands suitable for medium-scale environmental monitoring (Garai & Narayana, 2018; Saini *et al.*, 2016). Specifically, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images were used for 2005 and 2010, while Landsat 8 Operational Land Imager (OLI) imagery was used for 2015 and 2025, retrieved from the United States Geological Survey (USGS) Earth Explorer portal. To minimize cloud cover and seasonal vegetation variation effects, all images were acquired during the dry season, typically from November to March (Garai & Narayana, 2018).

Table 1. Data Characteristics

Satellite	Landsat 7		Landsat 8	
Sensor	ETM+		OLI	
Spectral Bands	8		11	
Spatial Resolution	30m		30m	
Temporal Resolution	16 days		16 days	
Image Years	2005, 2010		2015, 2025	
Source	USGS	Earth Explorer	USGS	Earth Explorer

Image pre-processing

Image pre-processing was conducted in a Geographic Information System (GIS) environment using ArcGIS 10.8 to ensure accuracy, consistency, and comparability across all years as prescribed by Tutmez *et al.* (2013). Pre-processing steps included: (i) Geometric Correction: All images were geo-referenced to a common coordinate system, Universal Transverse Mercator (UTM), Zone 32 North, based on the WGS 1984 datum. This allowed pixel-based comparison for accurate classification and transition analysis. (ii) Radiometric Correction: Spectral quality and brightness variations between sensors were harmonized using radiometric correction to ensure consistent reflectance values across the multi-temporal datasets. (iii). Scan Line Correction: Gaps in Landsat 7 imagery due to sensor striping were corrected using a gap-filling approach.

Land Use and Land Cover Classification

We applied supervised classification using the Maximum Likelihood Classifier (MLC) algorithm to categorize LULC across all years. MLC was selected due to its robustness in assigning pixels

to land cover classes based on the statistical distribution of training data (Saini *et al.*, 2016). We generated training samples for each LULC class by digitizing polygons using field surveys and high-resolution Google Earth imagery as a reference.

LULC classes were defined as follows:

Vegetation: Natural forests, shrubs, and grasslands; Farmland: Cultivated and fallow agricultural fields; Bare Surface: Exposed soils, mining pits, and waste dumps; Water Bodies: Rivers, ponds, and mining-induced water catchments; Settlements: Residential and infrastructural developments. Each year's imagery was classified separately to allow temporal comparisons.

Change Detection and Transition Analysis

To quantify spatial and temporal dynamics, we conducted transition analyses for 2005–2010, 2010–2015, and 2015–2025. Transition matrices were generated to evaluate LULC conversions, indicating stable areas (e.g., vegetation to vegetation), degraded areas (e.g., vegetation to bare surface), and recovering areas (e.g., bare surface to vegetation). This approach enabled statistical and spatial interpretation of the magnitude, direction, and patterns of LULC change (Ceballos *et al.*, 2015; Steffen *et al.*, 2015).

RESULTS

Land Use and Land Cover Dynamics

Visual and quantitative analysis of multi-temporal satellite imagery revealed noticeable changes in land use and land cover (LULC) in the Maiganga coal mining area between 2005 and 2025. The LULC classes — vegetation, farmland, bare surface, water bodies, and settlement—showed variations indicative of both mining impact and reclamation efforts (Table 2)

Table 2. Land Use Land Cover Classes (m²) from 2005 to 2025

Class / Year	2005	2010	2015	2025
Vegetation	3,560	11,080	6,010	10,200
Farmland	14,070	7,771	11,550	7,530
Bare Surface	1,390	900	1,080	1,310
Water Body	180	100	730	500
Settlement	670	40	510	340
Total	19,870	19,891	19,880	19,880

Results show that farmland accounted for the largest proportion of LULC throughout the study period, though it fluctuated significantly between 2005 and 2010 (Table 2). Interestingly, farmland decreased from 14,070 m² to 7,771 m², likely due to fallowing or conversion to vegetation as part of reclamation activities. By 2015, farmland recovered to 11,550 m² before decreasing again to 7,530 m² in 2025. Vegetation cover showed a general increasing trend, reflecting the positive effects of reclamation through afforestation and reforestation (Table 2). Bare surfaces exhibited minor variations, indicating limited expansion of exposed land despite ongoing mining activities. Water bodies appeared sporadically due to mining-induced ponds, while settlements remained the least extensive LULC class, with small fluctuations over the 20 years. Settlements established outside the mining area left open spaces for coal extraction, which were later replaced by tree plantations (Neem, Eucalyptus and Mahogany) through the company's afforestation and reforestation efforts. However, the operational offices (administrative, Clinic and Lodge) were constructed at the

commencement of mining in 2005. This accounts for the minor shifts or changes in the overall area that transformed into new settlements after the relocation of the original settlements.

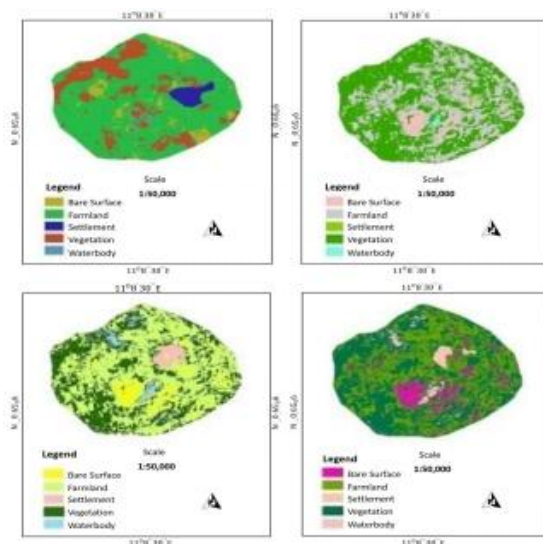


Figure 2. Spatial Distribution of LULC Transition Analysis

LULC Transition Analysis

To better understand LULC change dynamics, we analyzed transition matrices for three intervals: 2005–2010, 2010–2015, and 2015–2025. The results highlight patterns of stability, degradation, and recovery (Table 3).

Table 3. LULC Transition Matrices (2005–2010; 2010–2015; 2015–2025, m²)

LULC Change	2005 - 2010 Area (m ²)	2010 - 2015 Area (m ²)	2015 - 2020 Area (m ²)
Bare surface to Bare surface	194	853	356
Bare surface to Farmland	611	24	5
Bare surface to Settlement	0.9	20	1
Bare surface to Vegetation	581	0.05	36
Bare surface to Water body	11	2	7
Farmland to Bare surface	890	215	239
Farmland to Farmland	6,120	7,180	7,318
Farmland to Settlement	144	359	74
Farmland to Vegetation	6,801	23	3,929
Farmland to Water body	122	0.2	0.001
Settlement to Bare surface	66	12	36
Settlement to Farmland	330	32	156
Settlement to Vegetation	270	0.06	99
Settlement to Water body	0.13	10	229
Vegetation to Bare surface	90	25	0.001
Vegetation to Farmland	453	4,321	60
Vegetation to Settlement	194	139	34
Vegetation to Vegetation	2,510	6,000	5,910
Vegetation to Water body	335	625	14
Water body to Bare surface	72	12	0.003
Water body to Farmland	30	0.008	0.0001
Water body to Settlement	0.8	0.2	0.0001
Water body to Vegetation	40	0.4	237
Water body to Water body	36	102	491

LULC Transition (2005 – 2010)

The transition matrix indicates that farmlands converted to vegetation (6,801 m²) represent widespread bush fallowing and early reclamation efforts. Bare surfaces largely reverted to vegetation (581 m²) or farmland (611 m²), suggesting partial restoration of degraded land. Vegetation loss occurred mainly to farmland (453 m²) and water bodies (335 m²), reflecting localized soil disturbance or pond formation from mining operations (Table 3).

LULC Transition (2010–2015)

Between 2010 and 2015, vegetation stability remained high (6,000 m²), while farmland remained stable (7,180 m²) and converted to settlement (359 m²), indicating localized human settlement expansion. Bare surface areas largely remained stable, reflecting limited new land degradation (Table 3).

LULC Transition (2015–2025)

During 2015–2025, substantial farmland-to-vegetation conversion (3,929 m²) highlights ongoing reclamation and afforestation efforts (Table 3). Vegetation stability remains significant, while settlement and bare surfaces show minimal expansion.

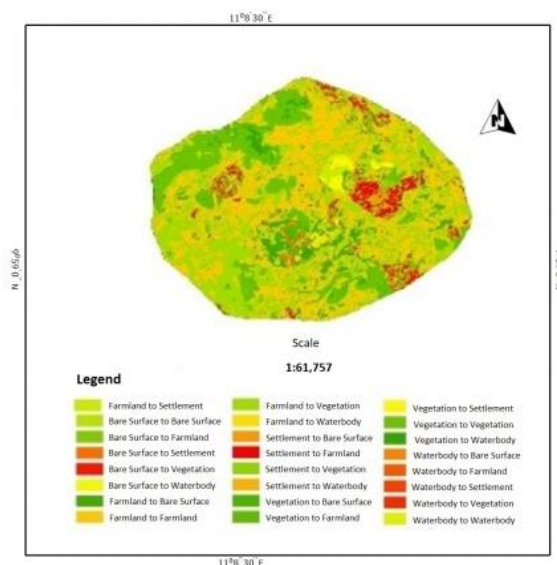


Figure 3: Spatial Distribution of LULC Transition Analysis (2005 – 2010)

Spatial Distribution

Figures 2–5 illustrate the spatial distribution of LULC classes and transitions across the 20-year study period. Vegetation and farmland transitions dominate the landscape, whereas settlement and bare surfaces are spatially constrained. Water bodies are localized, reflecting mining-induced pond formations in excavated areas.

Overall, LULC analysis shows that while mining activities caused temporary degradation, progressive reclamation efforts by Lafarge Africa and Ashaka Cement have positively influenced vegetation recovery. Farmland fluctuations correspond to land management and economic use, while bare surface areas and settlements remained relatively minor. These results demonstrate the resilience of the Maiganga landscape under managed mining and reclamation interventions.

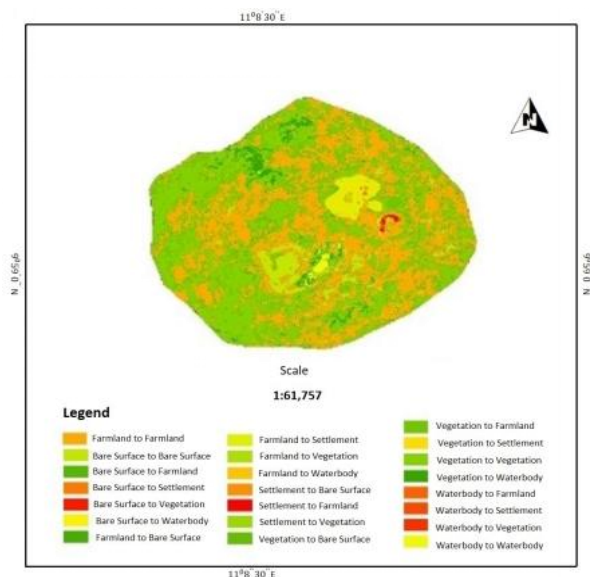


Figure 4: Spatial Distribution of LULC Transition Analysis (2010 – 2015)

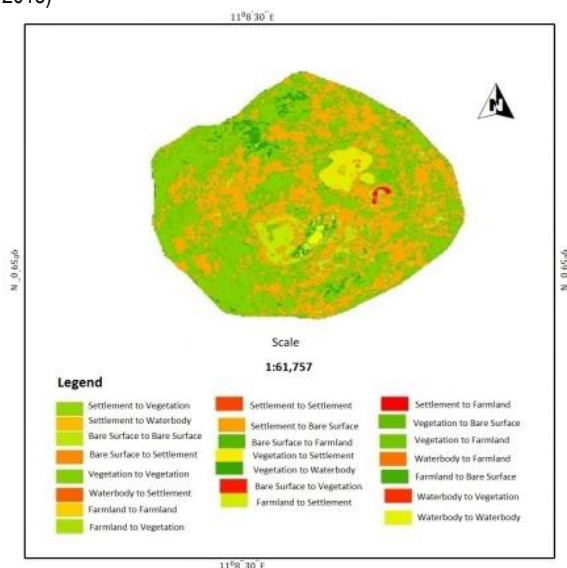


Figure 5: Spatial Distribution of LULC Transition Analysis (2015 – 2025)

DISCUSSION

Human activities have transformed more than one-third of Earth's land surface, and Land Use and Land Cover (LULC) changes are a major driver of global climate change (Winkler *et al.*, 2021; Muche *et al.*, 2023; Afuye *et al.*, 2024). This study contributes to the growing body of evidence emphasizing the need for a holistic approach to environmental management—one that integrates ecological, socio-economic, and spatial dimensions (Suzanchia, 2011). Such an approach is critical for understanding and mitigating the complex impacts of LULC dynamics on ecosystem functions, biodiversity, and climate systems (Ceballos *et al.*, 2015; Garai & Narayana, 2018).

The company's reclamation strategy demonstrated a comprehensive understanding of mining's multifaceted impacts on

the landscape. The company holistically addressed key environmental disturbances—such as the emergence of water bodies contaminated with heavy metals, destruction of native flora, and displacement of soil fauna—and integrated them into the reclamation action plan.

To mitigate soil degradation and air pollution from particulate discharge, tree-planting initiatives (Plate 1 & 2) were implemented. These trees and surrounding vegetation provided canopy cover and absorbed airborne dust particles, reducing pollutant spread. Additionally, soil integrity and structure were restored through natural processes such as root stabilization and leaf litter accumulation, which promoted soil aggregation and nutrient cycling (Plate 5).

Water-related impacts were also carefully managed. Wastewater and groundwater contamination were initially treated by constructing a sedimentation pond, which facilitated physical filtration (Plate 4). This was complemented by the creation of an artificial wetland (Plate 3) designed for phyto-depuration — a biological process that uses plants to remove contaminants — thereby enhancing water quality and supporting ecological recovery.

The observed Land Use/Land Cover (LULC) changes in the study area reveal a nuanced interaction between anthropogenic activities and environmental dynamics (Wells, 2025). Notably, the minimal distortion in original land use functions before mining suggests that certain preexisting land uses remained resilient despite extractive pressures. This resilience is further highlighted by the establishment of tree plantations and orchards (Plate 1 & 2), which have enhanced the vegetation structure and improved the spatial distribution of tree cover across the landscape.

Moreover, the expansion of agricultural land outside the mining zones reflects a strategic adaptation to environmental conditions. Near-perennial water availability from mining-related hydrological alterations (Plate 4) has enabled off-season farming through irrigation, supporting food security and rural livelihoods.

These findings align with broader research indicating that environmental impacts on agricultural land, built-up areas, bare land, and forest cover can be significantly mitigated through conscious remedial actions during resource extraction (Rahman *et al.*, 2023; Shiferaw *et al.*, 2023; Chisanga *et al.*, 2024). Such interventions not only reduce degradation but also safeguard biodiversity, water resources, and climate regulation (Ancha *et al.*, 2021; Nsor & Nya, 2025).

Importantly, the study emphasizes the need to contextualize land cover changes within the specific landscape and prevailing environmental forces. For instance, attributing increases in bare areas exclusively to mining is misleading, as natural processes like erosion and landslides may also contribute (Rowland & Ebuka, 2024). A landscape-sensitive approach is therefore essential for accurate environmental assessments and sustainable land management.

The Land Use/Land Cover (LULC) changes documented in this study offer valuable insights for strategic planning at local, regional, and global scales, particularly for projects involving resource extraction and landscape transformation. Global neglect of LULC dynamics has severe ecological consequences, including disruption of ecosystem functions, habitat degradation, and species extinction (Abdulsalam *et al.*, 2016; Ceballos *et al.*, 2015; Abebe *et al.*, 2022). Our findings reinforce the critical role of

temporal LULC models, which capture conversion and transition over time and enable a deeper understanding of the drivers and patterns of change.

Spatial distribution analysis further highlights the utility of these models in distinguishing between anthropogenic and natural influences on land cover. For example, the formation of water bodies and the establishment of tree plantations through afforestation and reforestation are best appreciated through a spatio-temporal lens spanning two decades. Such long-term observation reveals ecological transformations that might otherwise be overlooked (Chisanga *et al.*, 2024).

One notable outcome is the emergence of wetlands, which has increased avian diversity and the settlement of water-dependent bird species (Plate 6) previously absent from the pre-mining landscape (Nsor & Nya, 2024; Nsor *et al.*, 2022). These avian interactions contribute significantly to ecosystem functions, including nutrient enrichment via fecal deposits on agricultural fields, as well as pollination and seed dispersal (Tela *et al.*, 2021). These findings underscore the interconnectedness of land cover dynamics and ecological health, emphasizing the need for informed, adaptive land management strategies.

Conclusion

This study examined land use and land cover (LULC) changes in the Maiganga coal mining area over twenty years (2005–2025), focusing on the impacts of mining activities and the effectiveness of progressive reclamation efforts. The analysis initially showed substantial alterations in vegetation, farmland, and bare surface areas, reflecting anthropogenic pressures on the landscape. However, reclamation strategies, including afforestation and land restoration, contributed to a notable recovery in vegetation cover, indicating that rehabilitation measures can mitigate some negative ecological impacts of coal extraction.

Farmland: both following and land conversion practices, highlighting the interaction between human agricultural activity and landscape management. Bare surfaces remained limited in extent, suggesting reclamation efforts effectively reduced exposed land vulnerability. Water bodies, formed mainly by mining operations, were spatially restricted and fluctuated according to rainfall and mining dynamics. Settlement areas reflected controlled human encroachment within the mining field.

Overall, the findings underscore the importance of continuous monitoring in mining regions and demonstrate that progressive reclamation can restore ecological functions, enhance vegetation resilience, and reduce the adverse effects of land degradation. These results provide empirical evidence for policymakers, mining companies, and environmental managers, emphasizing the need to integrate sustainable land management practices alongside industrial development to preserve both biodiversity and community livelihoods.

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Plate 1. Tree Plantation established in 2021



Plate 2. Tree Plantation established in 2009



Plate 3. Artificial Wetland Afforestation area



Plate 4. Sedimentation Pond



Plate 5. Reclaimed landfill area undergoing



Plate 6. Active mine pond inhabited by White-forested and soil consolidation Face whistling ducks and other species of birds