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Temporal Analysis of Vegetal Cover in Coal Mining Areas of Ankpa LGA, Kogi State, Nigeria

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ABSTRACT

Globally, coal mining is recognized as an inherently economically important process, regrettably, it promotes landscape destruction through deforestation, erosion, pollution, and disruption of soil properties which have direct link to vegetation loss. This research is therefore is on the temporal analysis of vegetal cover in coal mining areas of Ankpa Local Government Area, Kogi State, Nigeria. This research was guided by three (3) research questions and objectives. A quasi- experimental and longitudinal research design was used for the study. Remote Sensing and Geographic Information System (GIS) was used as instrument to collect imageries covering the year 2004, 2014 and 2024. Satellite imageries and GIS data were sourced from United States Geological Survey (USGS) Earth Explorer, Global Land Cover Facility (GLCF) and National Space Research and Development Agency (NASRDA). Data generated were analyzed by supervised image preprocessing, land cover classification, vegetation cover analysis, change detection analysis, Normalized Difference Vegetation Index (NDVI), spatial and temporal analysis, and ground truthing using Arc GIS 10.1 and ERDAS Imagine 9.0 software. Findings show that the aerial extent of vegetation cover was 58.0% (767.75km^2) in 2004, 58.0% (767.75km^2) in 2014 and 58.0% (767.75km^2) in 2024. Also, vegetation declined significantly from 58.0% (767.75km^2) in 2004 to 18.0% (238.27km^2) in 2024 which was as a result of anthropogenic activities such as coal mining. Results from the NDVI index for the years 2004 (0.240223 and -0.337662), 2014 (0.461684 and -0.108356), and 2024 (0.342161 and 0.00820448) indicating an unhealthy vegetation in the study area. It was recommended among others that stringent mitigation measures, including reforestation, sustainable mining practices, and community-based conservation efforts should be implemented. Effective policy enforcement, alternative livelihoods, and the adoption of green technologies will further help balance economic development with environmental preservation.

Key words: Coal, mining, vegetal cover, GIS, Remote Sensing

Introduction

Coal mining is a global activity with considerable environmental impacts, particularly on vegetation cover. In countries like the United States, Germany, and Australia, coal has historically driven economic growth but caused deforestation, habitat destruction, soil erosion, and water pollution due to open-pit mining and improper waste disposal (Diachenko & Dyatel, 2020; Oruonye, Iliya & Ahmed, 2016; Bureau of Land Management, 2019). Similar environmental degradation is reported in tropical rainforests in Indonesia and Brazil, where coal extraction contributes to biodiversity loss and climate change through forest clearance and carbon emissions (Nguyen, 2021). Heavy machinery, blasting, and road construction often lead to further degradation by compacting soils and introducing contaminants (Singh et al., 2020). In response, international organizations and governments are implementing environmental impact assessments, reclamation practices, and stricter regulations to reduce coal's ecological footprint (Srivastava & Raghubanshi, 2021; International Energy Agency, 2021; UNEP, 2020).

In Nigeria, coal mining has played a significant role in the economy, particularly in Enugu, Ebonyi, and Kogi States. Mining activities in Ankpa Local Government Area began in Odagbo in 1967 and expanded over the decades (Obaje, 2009; Oloche, Gabriel & George, 2019). Although coal contributed to industrialization and energy development during the colonial and post-independence eras (Ebohon, 2017), recent years have seen growing concerns about its environmental consequences. Ankpa's rich vegetation including forests, savannas, and wetlands are under increasing threat from mining expansion (Ikegwuonu, 2018; Ambursa et al., 2021). While Nigeria has introduced environmental regulations and mandates Environmental Impact Assessments (Ogbonna, Nzegbule & Okorie, 2014), enforcement remains weak, allowing unchecked resource exploitation (Okorie & Egila, 2014). Social impacts such as displacement, loss of livelihoods, and land conflicts have further heightened the need for sustainable and regulated mining practices (Pretty & Odeku, 2017; Chukwuka et al., 2023).

Over time, it has been discovered that certain environmental changes are irreversible, while others are reversible and generated by a variety of human actions. Changes in land use procedures can have both positive and negative economic, social, political, and environmental consequences (Horn, 2018). Land use data provides the foundation for understanding historical and contemporary human interactions with natural resources and the environment.

The development of air and space borne remote sensing has enabled the collection of consistent before and post-project land use data (Grippa et al. 2020). Furthermore, the development of Geographical Information Systems (GIS) has enabled the integration of multisource and multidate data for the creation of land use/land cover changes, including trend, rate, type, location, and magnitude of changes (Zhong, Gong, & Biging, 2020).

Historically, the majority of land information has been obtained from direct observations in the field utilizing previously surveyed base maps and aerial pictures. However, the introduction of remote sensing techniques using satellites such as the American Land Sat series, the French Spot, and the Nigeriasat-1, as well as computer-based Geographical Information Systems (GIS) capable of processing and comparing large amounts of data, has resulted in more detailed and accurate land use information. Mixed mosaics of multiple land uses may now be properly mapped, and changes in land use can be tracked on a fine scale. Many academics have used remote sensing and GIS to examine the changes in land use (Dutta, Das, & Aryal, 2016; Musa, Hashim, & Reba, 2020).

Statement of the Problem

Despite the economic significance of coal, coal mining in Ankpa has led to slow vegetation recovery, deforestation, habitat loss, and soil degradation (Oruonye, Iliya & Ahmed, 2016; Adesoji & Awotoye, 2019). Advanced techniques like remote sensing have been used in other countries such as China's Liaoning Province to assess long-term vegetation trends and inform reclamation efforts (Ma et al., 2021; Ashish et al., 2021), but such technologies are largely absent in studies of Ankpa. Indices like the Normalize Differential Vegetation Index (NDVI) have not been applied to evaluate vegetation health in this region. This study therefore seeks to fill these gaps by using satellite imagery, GIS tools, and ground truthing data to identify the aerial extent, the level of vegetation loss and the vegetation health in coal mining areas of Ankpa LGA.

Research Questions

To guide this research, the following research questions were formulated.

i. What is the aerial extent of vegetation cover in coal mining areas of Ankpa Local Government Area, Kogi State in the years 2004, 2014 and 2024?

ii. What is the level of change (loss) in vegetation cover between 2004, 2014 and 2024 in the study area?

iii. What is the vegetation health (NDVI) of the coal mining areas in the years 2004, 2014 and 2024?

Study Area

Ankpa is the administrative headquarter of Ankpa Local Government Area situated in the eastern part of Kogi State. It lies between latitude 7º16′N and 7º41′N of the equator and longitude 7º22′E and 7º51′E of the Greenwich Meridian. It is bounded by Omala Local Government Area to the North, to the east by Oturkpo LGA in Benue State, to the west by Ofu and Dekina Local Government Areas and to the south by Olamaboro Local Government Area. Ankpa mining areas include Odagbo (Okaba), Okobo/Okpokwu, Enjema, Odokpono, Olokwu, and Ikah/Awulu/Manejo/Ikah Ogboyaga (all in Enjema and Ojoku Districts).

Fig 1: Kogi Showing Ankpa LGA and the Study Area

Coal exploration activities

Coal exploration activities encompass a range of processes involved in the search for coal deposits, from initial surveys to advanced exploration techniques. These activities typically begin with desk-based studies and geological mapping to identify potential coal-bearing areas (Ghose, 2021). Once potential sites are identified, field surveys are conducted to assess the geological characteristics, including coal seam thickness, depth, and quality (Ambursa, Muhammad, Bello, Alhassan, & Abdulrahman, 2021).

Following initial surveys, coal exploration progresses to more detailed assessments, such as drilling and sampling. Drilling involves the extraction of core samples from the subsurface to determine the extent and quality of coal deposits (Garai, & Narayana, 2018). These samples are analyzed for coal content, ash content, calorific value, and other parameters to assess the economic viability of mining operations (Hasan, Rashid, & Paul, 2015). Upon confirming the presence of economically viable coal reserves, exploration activities intensify, leading to land clearing and infrastructure development. This phase involves the construction of access roads, drill pads, and other facilities necessary for mining operations (Adesoji & Awotoye, 2019). Land clearing involves the removal of vegetation and topsoil to expose coal seams and prepare the site for excavation (Diachenko & Dyatel, 2020).

Subsequently, coal extraction begins, employing various mining techniques such as surface mining (open-pit or strip mining) or underground mining (shaft or drift mining) depending on the geological characteristics of the deposit (Ambursa, Muhammad, Bello, Alhassan, & Abdulrahman, 2021). Surface mining involves the removal of overlying rock and soil to access coal seams, while underground mining entails tunneling into the earth to reach coal deposits (Ghose, 2021). Throughout the exploration process, environmental considerations and regulatory requirements are crucial. Environmental impact assessments (EIAs) are conducted to evaluate the potential impacts of coal exploration activities on the surrounding environment and communities (Garai, & Narayana, 2018). Mitigation measures, such as reforestation, rehabilitation of mined areas, and dust suppression techniques, are implemented to minimize environmental degradation and mitigate adverse effects on vegetation and ecosystems (Hasan, Rashid, & Paul, 2015).

In summary, coal exploration activities encompass a series of systematic processes, from initial surveys and geological assessments to land clearing, infrastructure development, and coal extraction. These activities play a significant role in shaping the environmental landscape and have profound implications for vegetation dynamics and ecosystem health in coal-producing regions.

Vegetation dynamics

Vegetation dynamics is the science about the concepts, theories, observations, and models that deals with changes in vegetation over time (Levente & Mohamed, 2023). Changes in vegetation are a constant phenomenon on Earth. Vegetation dynamics refers to the continuous changes in plant communities over time due to natural and anthropogenic factors. These changes can be driven by ecological succession, climatic variations, disturbances, and human activities, influencing biodiversity, ecosystem stability, and land cover patterns (Pickett et al., 1987). Vegetation dynamics encompass the processes of growth, competition, mortality, and regeneration that shape plant communities. Understanding these dynamics is crucial for ecosystem management, conservation planning, and predicting responses to environmental change (Fischer et al., 2016). It is a dynamic process influenced by ecological succession, climate variability, land use changes, and human interventions (Lambin et al., 2003).

Vegetation dynamics in coal mining areas are significantly influenced by coal exploration and mining activities, leading to spatial and temporal changes in vegetation cover, species composition, and ecosystem structure (Adesoji & Awotoye, 2019). One of the primary impacts on vegetation dynamics is deforestation and habitat destruction resulting from land clearing for mining operations (Garai, & Narayana, 2018). This alteration of land cover disrupts ecosystems, fragments habitats, and reduces biodiversity, leading to changes in species composition and distribution (Diachenko & Dyatel, 2020). Moreover, coal exploration and mining activities can result in soil degradation and erosion, further impacting vegetation dynamics (Ambursa, Muhammad, Bello, Alhassan, & Abdulrahman, 2021). The removal of topsoil and vegetation exposes soil to erosion by wind and water, leading to sedimentation of water bodies and loss of soil fertility (Hasan, Rashid, & Paul, 2015). Soil compaction and contamination from mine waste materials further restrict the growth of vegetation, affecting plant establishment and ecosystem regeneration (Ghose, 2021).

Remote sensing

Remote sensing has grown dramatically in recent years, reflecting technological breakthroughs and the rising necessity of understanding and monitoring our world. Remote sensing is the art and science of gathering information about an object, location, or phenomena without making direct physical touch with it (Lillesand et al., 2021). Remote sensing is described as the science of getting information about an object, region, or phenomena by analyzing data collected by a device that is not in contact with the object, area, or phenomenon being studied (Pinheiro et al, 2021). According to a 2020 evaluation by the National Oceanic and Atmospheric Administration (NOAA), remote sensing comprises a wide variety of technologies and methods, such as satellite imagery, aerial photography, and ground-based sensors. These technologies enable the collection of data on a wide range of environmental, social, and economic variables, such as land cover, vegetation, water resources, and infrastructure. One of the primary advantages of remote sensing is its capacity to give a complete and current view of the Earth's surface and atmosphere (NASA, 2021).

Geographic Information System (GIS)

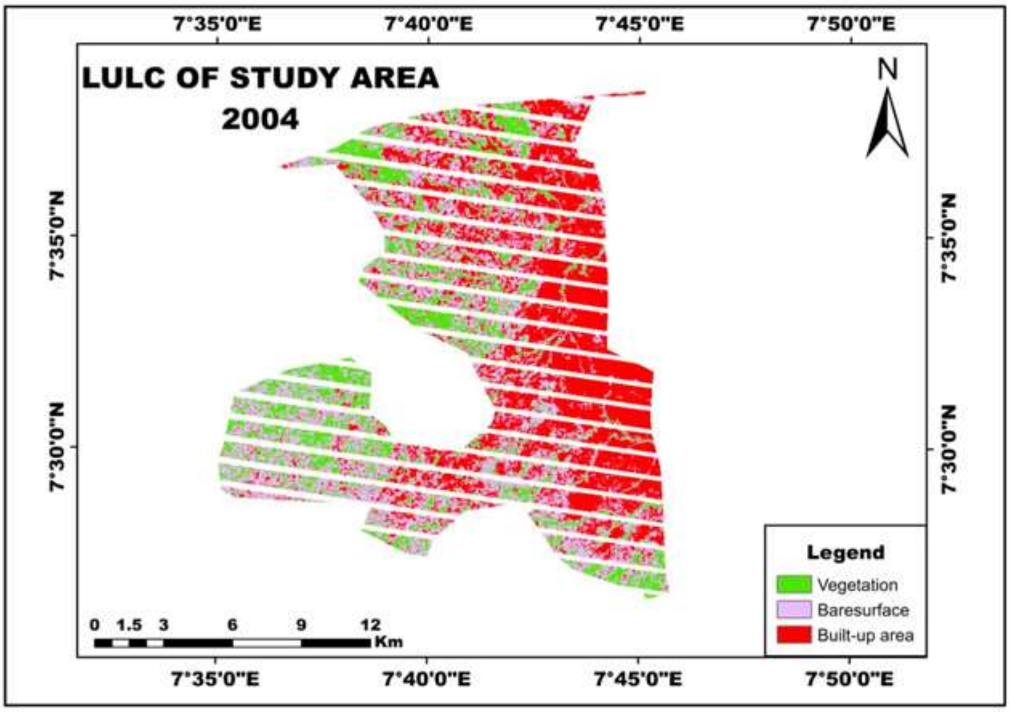
There are several meanings for the word geographic information system (GIS), each established from a unique standpoint or disciplinary provenance. Some highlight the map link, others the database or software toolkit, and yet others applications like decision assistance. One of the most general definitions was created by consensus among 30 professionals, as follows: Geographic Information System- A system of technology, software, data, people, organizations, and institutional structures used to gather, store, analyze, and disseminate information about geographical locations (Chrisman, 1997). A Geographical Information System (GIS) is a computer-based system that collects, stores, manipulates, analyses, and displays geographic or spatial data (Longley et al., 2021). A Geographic Information System (GIS) provides a framework for data collection, management, and analysis. GIS, which is based on geography, combines a wide range of data kinds. It analyzes physical location and layers of information to create visualizations with maps and 3D sceneries." (National Geographic, 2022). A Geographic Information System (GIS) is a system for creating, managing, analyzing, and mapping various sorts of data. GIS links data to a map by combining location data (where objects are) with other forms of descriptive information. (US Geological Survey, 2024).

Research Methods

The study employed quasi-experimental and longitudinal research design. It is experimental research design through the use of Remote Sensing/ GIS techniques and longitudinal as it assess the changes in vegetation cover over time. Data required include satellite imageries of year 2004, 2014 and 2024, spatial data (GIS) on the locations and boundaries of active coal mining sites within the study area, ground-truthing data and ancillary data. Data were obtained from satellite imageries of different periods 2004, 2014 and 2024 of Ankpa, using Remote Sensing and GIS downloaded from the official website of Global Land Cover Data Facility (GLCF)-http://glcf.umiacs.umd.edu, Global Land Cover Facility (GLCF) and National Space Research and Development Agency (NASRDA). Also, ground truthing was conducted to validate and supplement the findings from satellite imagery analysis. Data generated from Remote Sensing and GIS on research the questions were analyzed by supervised image preprocessing using Arc GIS 10.1 software.

Findings of the Study

Aerial extents of vegetation cover in coal mining areas of Ankpa Local Government Area, Kogi State Vegetation cover for the year 2004



Source: Lab work, 2025

Fig. 2: Vegetation Cover map of coal mining sites in Ankpa LGA in 2004

Vegetation cover for the year 2014

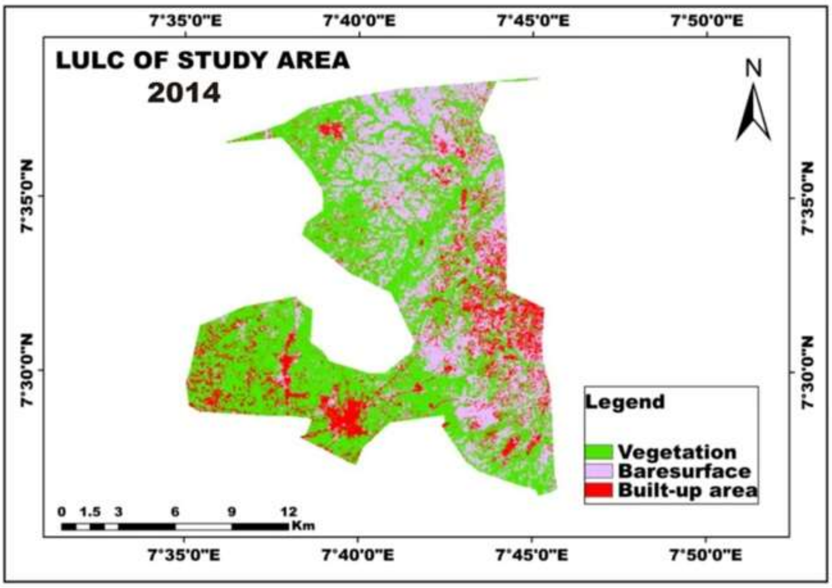


Fig. 3: Land Cover map of Ankpa LGA in 2014

Source: Lab work, 2025

Vegetation cover for the year 2024

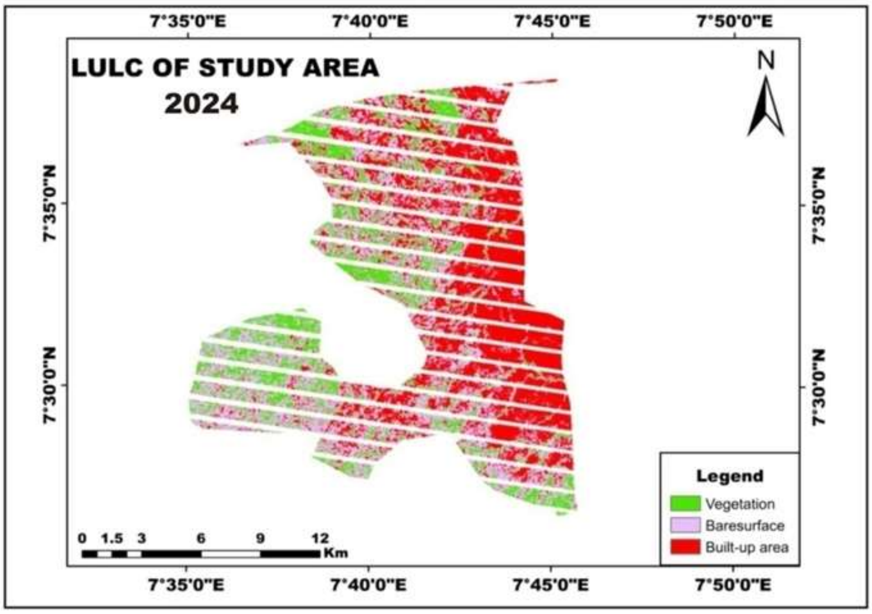


Fig. 4: Land Cover map of Ankpa LGA in 2024

Source: Lab work, 2025

Vegetation cover between 2004, 2014 and 2024

Table 1: Satellite imageries statistics on vegetation cover for 2004, 2014 and 2024

	2004		**2014**		**2024**	
Classes	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Vegetation	767.75	58.0	728.04	55.0	238.27	18.0
Bare Surface	370.64	28.0	330.93	25.0	463.30	35.0
Built-up area	185.32	14.0	264.74	20.0	595.67	45.0
Cloud cover	0.0	0.0	0.0	0.0	26.47	2.0

Source: Lab work, 2025

Aerial extent and level of change in vegetation cover

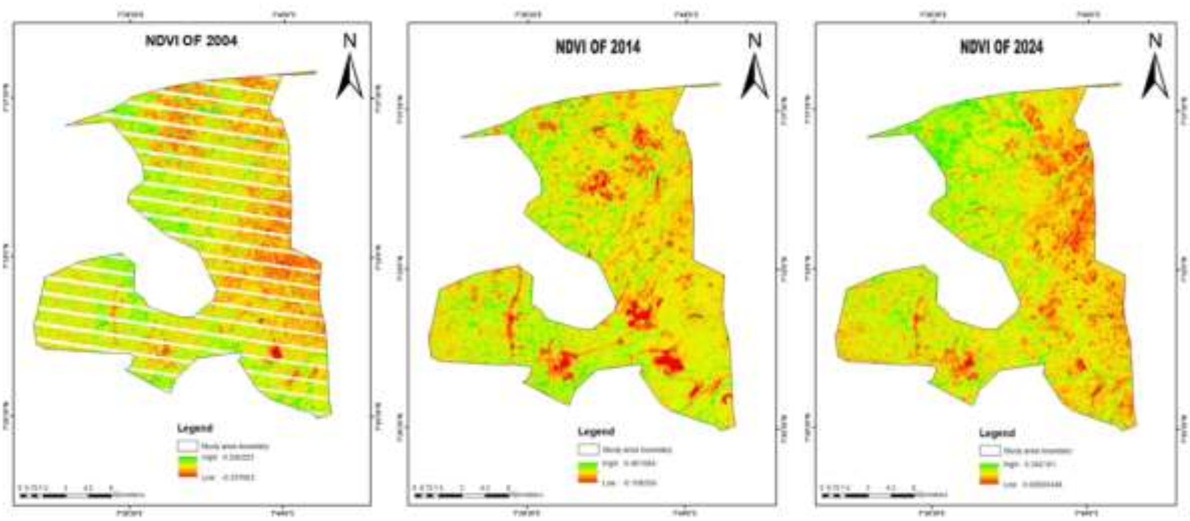
Figure 2 imagery depicts green areas as vegetation cover for the year 2004 with a percentage of 58.0. Vegetation covers nearly more than half of the total land area (1,323.71 km²), indicating that the coal mining areas had significant natural vegetation in 2004. The green areas are distributed across the map, but some parts appear to have fragmented vegetation, especially in areas mixed with settlements or bare surfaces. The large proportion of vegetative cover (58%) in Ankpa LGA as of 2004 is a critical baseline. This reflects the natural ecological integrity of the area prior to the extensive exploitation of coal resources. The dominance of vegetation aligns with the pre-mining phase of land use, characterized by secondary forests, shrubs, and grasslands typical of the Guinea Savanna zone of Nigeria (Ayuba et al., 2019). Coal mining in Ankpa intensified in the mid-2000s with industrial-scale extraction near towns such as Okaba and Awo. The 2004 land cover data, therefore, serves as the pre-disturbance snapshot against which later years (2014 and 2024) can be compared using NDVI and supervised classification in GIS.

Also, figure 3 shows Vegetation (728.04km², 55.0%) represented in green**,** this category dominates the map, covering more than half of the total land area. Vegetation is primarily found in the eastern and northern regions, with some patches in the southern part. The significant green cover indicates a relatively natural environment with forests, grasslands, or agricultural lands. Between 2004 and 2014, vegetation cover in Ankpa LGA declined by 39.71 km², representing a 5.17% loss over ten years. This reduction is significant and indicates a progressive degradation of vegetal ecosystems, a trend often associated with coal mining expansion, deforestation, and unregulated land conversion. However, the presence of built-up areas within vegetative regions suggests potential urban expansion into natural spaces.

Based on the map on figure 4 and the area statistics as generated by the GIS software on table 1, vegetation is represented in green and is scattered across the map, occupying 18.0% of the area and covering a land mass of 238.27 km^2 with higher concentrations in the north eastern part of the coal mining areas in Ankpa. The relatively low percentage (18.0%) implies significant land cover changes due to coal mining activities.

The satellite imagery statistics for 2004, 2014, and 2024 as shown on table 1 shows significant changes in vegetation cover, bare surface, built-up areas, and cloud cover over the years. Between 2004 and 2014, there was a decline in vegetation cover, reducing by 3%. However, by 2024, vegetation decreased significantly by 37%. This drastic reduction signifies accelerated deforestation or degradation of natural vegetation due to increased coal mining activities, urban expansion, and land-use change. The most significant loss occurred between 2014 and 2024, pointing to intensified anthropogenic pressure or policy lapses in environmental conservation.

Vegetation health of the coal mining areas in Ankpa for 2004, 2014 and 2024



The Normalized Difference Vegetation Index (NDVI) is a measure of vegetation health and density, often used for monitoring vegetation. It is calculated in GIS software by using a formula that combines reflectance data from the near-infrared (NIR) and red bands of satellite imagery. The formula is: (NIR - Red) / (NIR + Red) when calculating manually. If the raster layer shows a Green band, it is an indication for healthy vegetation, Yellow/brown for sparse vegetation and Blue for water or no vegetation. In interpreting the NDVI map, the raster calculator gives values that ranges from -1 to +1 and values close to +1 (reflectance) shows a healthy vegetation and close to -1 (absorbance) is an indication of unhealthy vegetation. When absorbance is very low (close to -1), it indicates a healthy vegetation but when it is high, it indicates an unhealthy vegetation.

The provided NDVI (Normalized Difference Vegetation Index) maps for the coal mining areas in Ankpa Local Government Area, Kogi State, Nigeria, over the years 2004, 2014, and 2024 reveal significant changes in vegetation health and cover. In 2004, the NDVI map shows relatively high vegetation cover, with the majority of the area displaying green colors indicating healthy vegetation. The NDVI values range from 0.240223 (high) to -0.337662 (low), suggesting a well-vegetated landscape at the time.

However, by 2014, the NDVI map depicts a slight decline in vegetation health and cover. The area is dominated by yellow and red colors, indicating a reduction in vegetation vigor and an increase in bare or sparsely vegetated surfaces. The NDVI values range from 0.461684 (high) to -0.108356 (low), suggesting significant land cover changes, likely due to the expansion of coal mining activities and associated infrastructure development. The 2024 NDVI map shows a noticeable deterioration and decline in vegetation health and cover. The landscape is further devegetated with NDVI values ranging from 0.342161(high) to -0.00820448 (low). This suggests that efforts have not been made to restore and rehabilitate the vegetation in the coal mining areas.

Discussion of Findings

The findings from the LULC analysis of Ankpa Local Government Area between 2004 and 2024 reveal significant temporal changes in vegetation cover. The drastic decline in vegetation cover from 58.0% in 2004 to 18.0% in 2024 clearly reflects the profound impact of coal mining operations on the local environment. This observation aligns with the findings of Adesoji and Awotoye (2019), who emphasized that coal mining activities are typically accompanied by extensive land clearing, leading to deforestation and significant habitat destruction. Also, Garai and Narayana (2018) noted that mining-induced deforestation disrupts ecosystems and fragments habitats, resulting in biodiversity loss.

Similarly, the sharp increase in bare surfaces from 28.0% in 2004 to 35.0% in 2024 further corroborates the environmental degradation associated with mining. As observed in related studies, mining operations expose topsoil and subsoil, making them vulnerable to erosion and sedimentation processes (Ambursa et al., 2021). The loss of soil fertility and structure observed in the study area mirrors findings by Hasan, Rashid, and Paul (2015), who documented the detrimental effects of mining-induced soil degradation on vegetation growth and ecosystem stability. The dramatic rise in built-up areas from 14.0% to 45.0% between 2004 and 2024 suggests rapid urban expansion, driven largely by infrastructural development to support mining activities. This pattern aligns with Diachenko and Dyatel (2020), who discussed how mining often stimulates urban sprawl and related land cover changes. However, this urbanization comes at a cost to natural vegetation and land sustainability, as reinforced by Adesoji and Awotoye (2019), who pointed out the adverse effects of mining-related urban expansion on ecological balance. These declines also have a direct effect on the vegetation health as revealed on the NDVI maps.

Conclusion and Recommendations

The findings indicate significant vegetation loss in coal mining areas of Ankpa Local Government Area over the years, primarily due to coal mining activities and land-use changes. The decline in vegetation from 58.0% in 2004 to 18.0% in 2024, suggests an extensive degradation of vegetation and vegetation health without subsequent restoration efforts. It is recommended that:

i. Reforestation and afforestation programs should be carried out within the coal mining areas.

ii. Strict environmental regulations must be enforced, requiring mining companies to conduct Environmental Impact Assessments (EIA) and adhere to sustainable mining practices.

iii. Alternative livelihood programs such as livestock farming should be introduced by the locales and the government to reduce dependence on coal mining.

iv. The adoption of green technology should be encouraged by the government.

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