Quest Journals
Journal of Research in Environmental and Earth Sciences
Volume 12 ~ Issue 4 (April 2026) pp: 01-06
ISSN(Online) :2348-2532
www.questjournals.org

Research Paper

Landscape Transformation and Carbon Stock Depletion in The Awka Capital Territory, Of Anambra State Nigeria Over a Thirty-Year Period (1993–2023)

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Abstract
The main cause of soil carbon loss is land use and land cover change (LULCC) which is caused by the high rates of urbanization and expansion of croplands. The present research is a 30-year quantitative study (1993-2023) of 30-year LULCC effects of carbon stocks in the Awka Capital Territory (ACT), Nigeria. Transitions in forest, shrubs, farmlands and built-up land were mapped using remote sensing of Landsat imagery and laboratory analysis of soil samples of six communities (Awgbu, Abagana, Awka, Nawgu, Urum and Agulu). Findings indicate that there was a radical change in the environment: urbanized regions grew by 383% and a percentage of urbanized areas decreased to 9.97 up to 48.15. This growth was at the cost of the natural cover as the forest cover decreased by 74 percent and shrublands by 64 percent. As a result, there were disintegration of carbon stocks in all land uses with losses of 79.1 percent in forests and 84. 8 percent in farmlands. The strong correlation between urbanization and carbon stock was also statistically validated to be negative (-0.93 < r -0.99), which shows that unsustainable land use has been the major contributor to carbon depletion within the region.

Keywords: *Land Use Change, Carbon Stock, Urbanization, Awka Capital Territory, Climate Change.*

Received 28 Mar., 2026; Revised 06 Apr., 2026; Accepted 08 Apr., 2026

I. Introduction

Land use and land cover change (LULCC) has been identified as being one of the main drivers of the change within the environment by the entire scientific community of the world (Nkonya, *et al.,* 2012). The shift in the land cover prevents energy, water and greenhouse gas (GHGs) exchange between the earth and the atmosphere. The anthropogenic activity, which is majorly the alteration of the surface of the Earth has reorganized the terrestrial carbon cycle (Bonan *et al.,* 2012). Land-use and land-cover change (LULCC) as Sleeter *et al.* (2018) observe, is an influential factor on climate and weather patterns since it alters the exchange of greenhouse gases. The importance of terrestrial ecosystems, namely soil and vegetation, as sinks of carbon cannot be overestimated in the context of the global climate change. These sinks however are becoming more and more sources of carbon releasing emissions as a result of irresponsible land management.

Land-use practices like deforestation, unacceptable bush burning and intensive tillage in Nigeria (the 44th largest contributor to the global emissions of CO_2 in 2010), have historically led to the net loss of soil carbon (C) to the atmosphere (Ndubuisi *et al.,* 2023). Land-use changes are a major contributor to the global warming in Nigeria, as the changes explain a good percentage of greenhouse gas emission profile in the country. Nigerian government, under its Nationally Determined Contributions (NDCs) under the Paris Agreement has pledged to cut down on the emissions by 20 percent to 45 percent by the year 2030 (Noah, 2025). To fulfil these goals, it is necessary to have a granular idea about the influence of local changes in the landscape on carbon sequestration.

The Awka Capital Territory (ACT), in the Anambra State in South-Eastern Nigeria is of paramount importance as a case study to these world trends in the environment. The area has undergone a fast and some cases unplanned urbanization, infrastructural development, and agricultural intensification since it was designated as a capital territory (Chunwate *et al.,* 2019). The resultant changes have meant a radical transformation of the natural eco-systems, like forest and shrubberies, to constructed-up areas and well-tilled agricultural lands. Zhang *et al.*

(2020) explain that urbanizing environments directly impact adaptive carbon sequestration management through land use change. This change in the ACT is typified by the substitution of biomass with a high carbon density with low-sequestration urban land uses.

Although the ACT has an ecological importance, there is an urgent need to know more about the empirical data on the certain effects of these 30-year changes on the potential of carbon sequestration in the regions. Earlier research within the area has in many cases concentrated on general urban growth or the fertility of soil yet limited studies have combined the remote sensing data with the laboratory based analysis of soil organic carbon (SOC) to measure the loss of carbon stock on the ground. The study fills this gap by evaluating the spatio-temporal performance of LULCC between the year 1993 and 2023.

The fact that clearing of natural vegetation to urbanize the land affects the soil and causes the soil to act as a carbon sink in the form of soil sealing, soil compaction and loss of organic matter makes the whole issue worse. Not only does this add to the carbon footprint in the world, but also augments other local environmental problems, like surface runoff, flooding and urban heat island effect. Yusuf *et al.* (2019) state that the agricultural and urban land use in the savanna areas of Nigeria is taking a toll on soil degradation.

This study would be the empirical foundation of sustainable land management by estimating the amount of carbon stocks changes and comparing the relationship between land cover shifts and sequestration collapse. The results will help city planners and environmental managers in the state of Anambra to come up with climate-sensitive land use policies. It is necessary to understand whether the ACT is a net carbon sink or source in addition to its role in regional climate mitigation policies and ecosystem services conservation in a fast-urbanizing West African landscape.

II. Materials and Methodology

Study Area

The study was carried out in the Awka Capital Territory (ACT) which is situated in the Anambra State in South-Eastern Nigeria. The ACT is defined by the existence of heterogeneous ecosystem with the presence of forest, savanna, grassland, and agricultural lands (Nzoiwu *et al.,* 2017). In order to have a representative evaluation of the effects of urbanization and change of land use, six communities were chosen namely Awgbu, Abagana, Awka, Nawgu, Urum and Agulu. These locations are a sample of different levels of urban development and agricultural activity in the capital land.

Data Sources and Sampling

The experiment combined spatial data on the geospatial level and primary measurements in the field (Burkholder, 2001). Land cover transitions were mapped on the basis of time-series analysis of the 1993, 2003, 2013 and 2023 Landsat satellite imagery (Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) Al Ramahie, 2012). This is a 30-year time interval enabled a thorough evaluation of decadal changes in land cover. Fieldwork entailed systematic soil samples collection through hand auger on the four recognized land-use categories, which are forest, shrubs, farmlands and built-up areas. Two different depths were used to collect samples in the topsoil (0-30 cm) and in the subsoil (30-60 cm) to calculate the vertical differences in the carbon storage.

Laboratory Characterization

The laboratory characterization aims at identifying the technology required to bring about the functionality of the laboratory; after collecting the samples in the field, they were taken to the laboratory to measure the essential physiochemical characteristics. The Walkley-Black chromic acid wet oxidation method was used in the determination of soil Organic Carbon (SOC) (Mylavarapu *et al.,* 2014). The clod method was used to measure bulk density which was necessary in the conversion of carbon concentrations into mass per unit area (Airori *et al.,* 2022). Moreover, the pH of the soil was determined in a 1: 2.5 mixture of soil and water to determine the chemical condition of the pools of soil carbon.

Carbon Stock Calculation

Soil Organic Carbon stock (SOC_{stock}) in tonnes per hectare (mg/ha) was quantified with the help of a standard formula that relates to the volumetric quantity. In this calculation, the carbon concentration is combined with the physical characteristics of the layer of soil:

$$SOC_{stock} = C \times BD \times d$$ (Tadiello *et al.,* 2020)

Where:

C = the percentage of Organic Carbon (%) obtained after laboratory analysis.

BD = the Bulk Density (g/cm^3).
d = the thickness of the layer of sampled soil (cm).

This methodology framework made it possible to directly translate the laboratory findings into a landscape level analysis of the carbon storage throughout the three decades of the study.

III. Results

Changes in Land Use and Land Cover (LULC)

The Awka Capital Territory (ACT) landscape changed completely during the thirty years of investigation between 1993 and 2023. The astronomical development of built-up areas was the most dominant trend with an increase by 383%. The amount of urban surface constituted 48.15% of the total territory by 2023 - almost half of the total territory in the city, which is a drastic by-pass of the 9.97 in 1993. This growth was done by systematically replacing the natural sources of carbon grouping, namely forests and shrublands, whose sectoral coverage dropped.

Analysis of Carbon Stock Depletion by Community

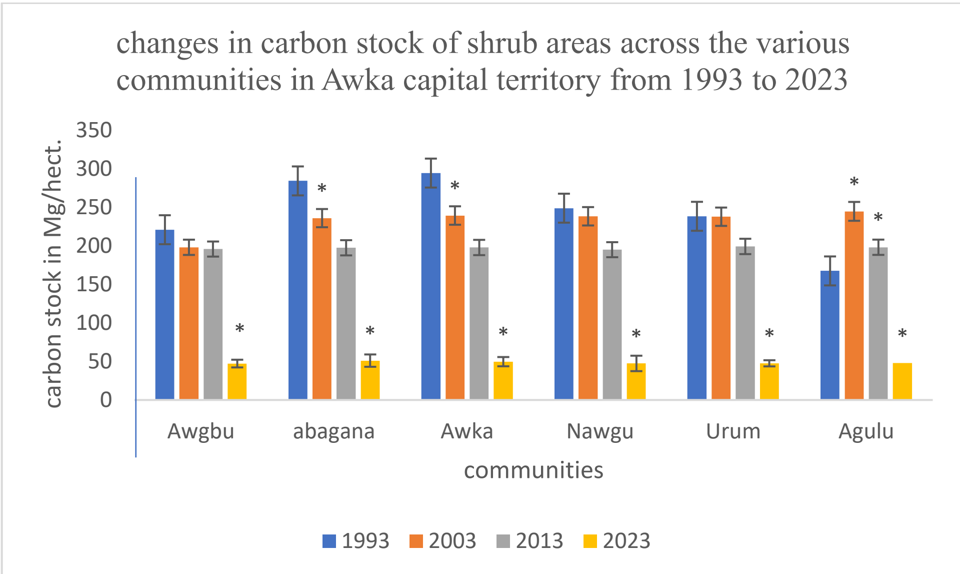
The carbon stock analysis when compared to the longitudinal analysis of carbon stocks in all the six communities showed a pattern of what is termed as a carbon collapse. Although the drop had been also gradual during the initial two decades, the most drastic and statistically significant decreases were registered between 2013 and 2023.

Table 1: Mean Carbon Stock and Land Cover Trends in ACT (1993–2023)

Year	Shrub Area Mean CS (mg/ha)	Shrub Area % Cover	Forest Area Mean CS (mg/ha)	Forest Area % Cover
1993	237.06	46.92	233.13	45.80
2003	232.22	35.05	234.93	30.67
2013	197.17*	25.55*	190.72*	20.13*
2023	48.70*	16.89*	48.77*	11.94*

*Significant ($p < 0.05$) compared to the previous decade.

Table 1 indicates that mean stock of carbon in the shrub areas declined as seen in 1993 (237.06mg/ha) to a pathetic 48.70 mg/ha in 2023. On the same note, the carbon stocks as measured by the forest area in mg/ha fell to 48.77 mg/ha as compared to 233.13 mg/ha. These stock cuts came with a significant decline in percentage cover with forest area reducing to only 11.94% (in 2023) having been 45.80% in 1993.



(Bars with asterix (*) are significant compared to the values of the past 10 years)

Figure 1: Changes in carbon stock of shrub areas across the various communities in Awka capital territory (ACT) from 1993 to 2023

The spatial pattern of these losses is also demonstrated in Figure 1, that shows variation in the carbon stock of the shrub regions in the different communities. The notable spikes in the figure underline the fact that the last decade is a very crucial tipping point of the regional sequestration potential.

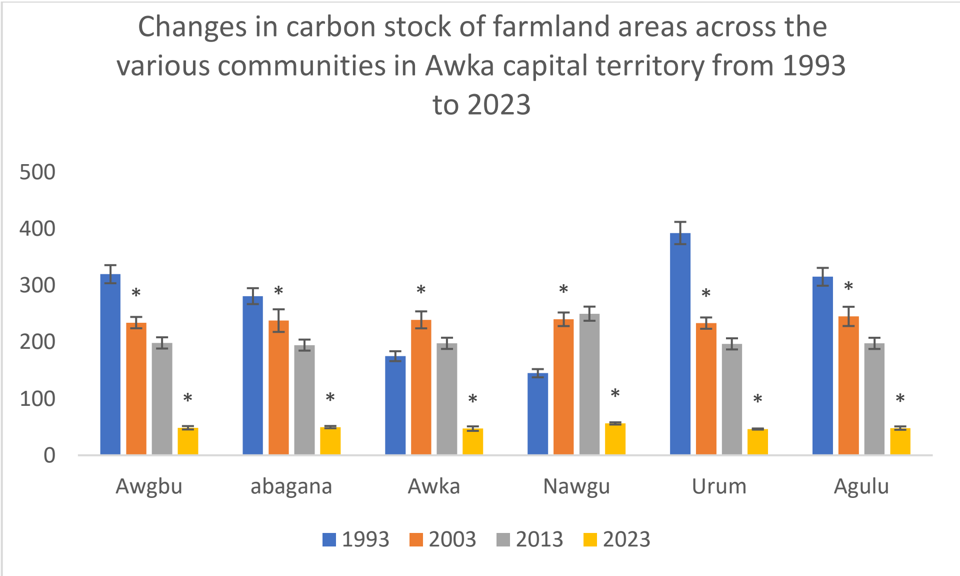
Community-Specific Findings

The information at the community level highlights the extent of the depletion. Agulu had the highest reduction in carbon stock in the forest whose values dropped to 49.43 mg/ha by 258.94 mg/ha which is an 80.9% loss. The category of the farmland recorded in Awgbu had an immense soil depletion with carbon reducing by 84.8% to 48.48 mg/ha.

Table 2: Changes in Farmland Areas and Carbon Stocks (1993–2023)

Community	1993 CS (mg/ha)	2023 CS (mg/ha)	% Reduction
Awgbu	320.19	48.48	84.8%
Abagana	281.51	49.33	82.5%
Agulu	258.94	49.43	80.9%

These reductions of farmlands are summarized in Table 2 with a pattern of depletion being the same in Awgbu, Abagana and Agulu. In Awka, the process of urbanization acceleration created urban centres at the very cost of almost all the natural carbon sinks. Such trends are graphically summed up in Figure 2, which traces the large decrease of carbon farmland stock during the thirty years.



(Bars with asterix (*) are significant compared to the values of past 10 years)

Figure 2: Changes in carbon stock of farmland areas across the various communities in Awka capital territory from 1993 to 2023

Correlation and Statistical Significance

The use of One way ANOVA and Pearson correlation proved that the principle cause of carbon loss was land use change. In the case of shrub, correlation coefficients (r) were between 0.89 and 0.99 with an ability to explain as much as 98% of carbon stocks. Most significantly, the built-up areas showed a very high inverse relationship between carbon stocks in all the study sites.

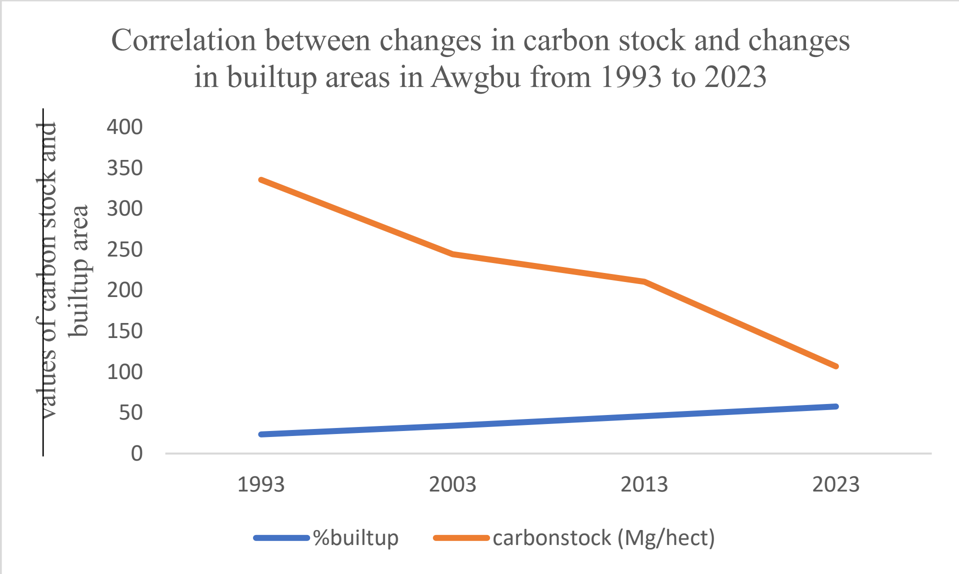


Figure 3: Correlation between changes in carbon stock and changes in built-up areas in Awgbu from 1993 to 2023

An example of this relationship is presented in Figure 3 where it can be seen that the expansion of built-up areas and the retention of carbon stocks in Awgbu are almost negatively correlated, with an expansion of built-up areas resulting in the virtual disappearance of the ability to store carbon.

IV. Discussion

The Mechanism of Carbon Sequestration Collapse

The results of this paper highlight a paradigm change of the environmental capacity of the Awka Capital Territory (ACT). The statistics indicate that direct conversion of land use was the major process of carbon loss as opposed to the gradual ecological destruction. The Urban surfaces in the form of low-carbon surfaces caused almost an instant loss of storage capacity as the high-carbon ecosystems, including forests and shrublands, changed to low-carbon urban surfaces. It is this soil sealing, heavy compaction and complete removal of the biomass that leads to this collapse. Although Sleeter *et al.* (2018) specify that land-cover changes alter the exchange of the greenhouse gases in the world, the effect is extreme locally in ACT, where the impervious urban surfaces irreversibly interrupt the biological processes involved in the carbon sequestration.

The Agricultural Treadmill Effect

The growth of the cultivation areas and the reduction of the carbon stocks were not connected as a critical observation in the farmland data. This means that there is a phenomenon of the so-called agricultural treadmill in the ACT communities. With reduced soil fertility and reduced carbon content caused by intensive tilling and insufficient fallowing, farmers are compelled to open up additional land in order to ensure production and this creates a cycle of growth and depletion. This result is in opposition to classical assumptions of agricultural expansion as a constant land use and rather follows Yusuf *et al.* (2019) who found that soil degradation in Nigerian savanna areas is at a tipping point with the result of unsustainable agricultural intensification.

Comparative Context and Regional Implications

The scale of carbon loss captured in this research (87% in certain sectors) is much higher than what has been recorded in the literature in the world. As an example, Don *et al.* (2011) conducted a global meta-analysis that approximated the loss of carbon in tropical soils as 25% in conversion of forest to croplands. The depletion rate of the ACT is significantly higher as it points to the strong stress of increased urbanization that doubled in 30 years (10 to 48%). Although this is reflective of other metropolitan areas in Africa that are high-growth, the results of the so-called carbon collapse in ACT makes a clear illustration of the danger of environmental harm that comes with uncontrolled urban sprawl in the Global South.

V. Conclusion

In the longitudinal evaluation of the Awka Capital Territory (ACT) between 1993 and 2023, the time of radical environmental change can be seen. The land has turned out to be a rich, forested carbon sink to an extremely degraded urban environment. The shift can be described as a 383% increase in built-up regions and an equivalent "carbon collapse" as the mean carbon stocks in forests, shrubs, and farmlands were reduced by 71% to

87%. There is statistical data to prove that urbanization is the main cause of this depletion which in effect seals the soil rendering the biomass unavailable to sequestration. Therefore, the ACT is at a greater risk of being exposed to the effects of climate change, such as, increased concentration of greenhouse gases, local flooding, and the worsening of the urban heat island effect.

Recommendations

Based on these results, it is possible to propose the following actions to reduce the additional carbon loss and strengthen the region:

i. Quick Preservation of Remaining Forest: The government ought to establish stringent zoning laws and conservation regulations to prevent additional urbanization of the 11.94% of forest cover of the ACT that remains.
ii. Incentivizing Sustainable Agriculture: To reverse the "agricultural treadmill effect the farmers need to be trained and incentivized to use sustainable methods including organic manuring and reduced tillage to replenish soil organic matter and stabilize the carbon stocks.
iii. Urban Green Infrastructure: The ministry of urban development should include green infrastructure such as urban parks, green roofs, and permeable pavements in the master plan of the capital ground. This will assist in repairing small carbon sequestration capacity and neutralizing the environmental pressures of high urbanization.

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