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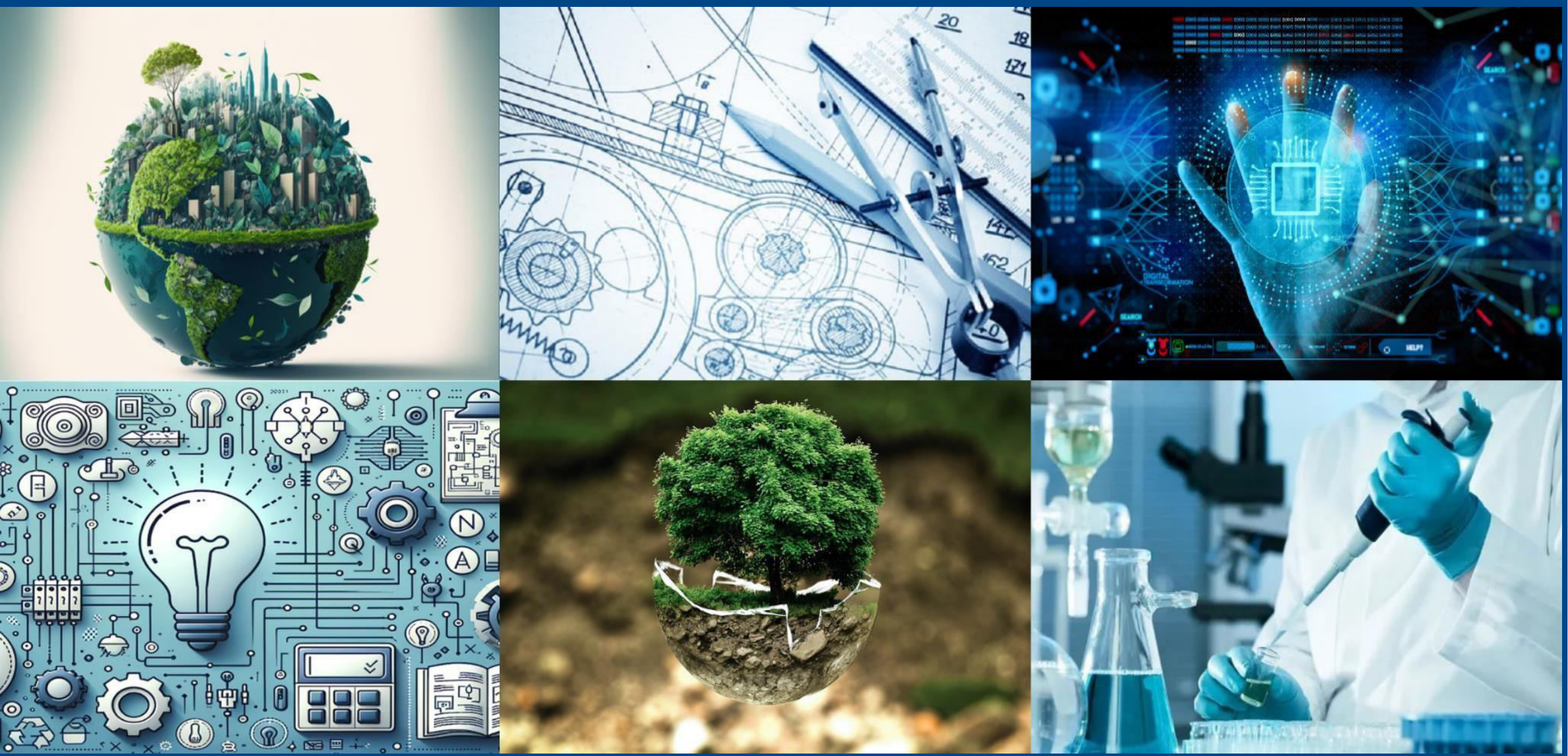

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Land Use Change and its Carbon Implications in Nigeria: A Critical Review of Influencing Factors and Research Trends

Similoluwa Abiodun Kadiri

School of Public Policy and Management, China University of Mining and Technology, Xuzhou, China

ABSTRACT: Land use change in Nigeria has intensified over recent decades due to rapid urbanization, agricultural expansion, deforestation, and infrastructure growth, resulting in significant carbon emissions and challenges to climate mitigation. This review synthesizes current empirical studies to assess how land use dynamics affect carbon fluxes within Nigeria's diverse ecological regions. Agriculture, urban growth, population pressure, and policy reforms emerge as dominant drivers of change. Most studies rely on remote sensing, GIS-based analyses, and carbon estimation methods like IPCC Tier 1/2 or ecosystem modeling frameworks. Findings reveal consistent patterns of forest loss, wetland degradation, and grassland conversion, leading to increased carbon release and weakened carbon sinks. However, methodological inconsistencies, limited ground validation, and sparse integration of socio-economic factors reduce the robustness and comparability of results. Northern Nigeria remains underrepresented in the literature, and there is a notable absence of region-specific emission factors and long-term monitoring efforts. The review highlights tensions between development goals and carbon conservation, calling for more balanced and inclusive research. It underscores the need for harmonized methodologies, better-quality data, and interdisciplinary approaches that bridge ecological, social, and policy domains. Addressing these gaps is critical to guiding effective land management and climate policy tailored to Nigeria's regional complexities and sustainability ambitions.

I. INTRODUCTION

Land use change (LUC) refers to the transformation of the natural landscape through human activities such as agriculture, urbanization, industrial expansion, and infrastructure development. These transformations exert significant influence on terrestrial carbon stocks and greenhouse gas emissions, thereby playing a central role in the global carbon cycle [1, 2, 3]. The clearing of forests, draining of wetlands, or conversion of grasslands often leads to the release of carbon stored in biomass and soils into the atmosphere, contributing to climate change [4, 5, 6]. Conversely, sustainable land management practices such as afforestation, agroforestry, and conservation agriculture offer considerable potential for carbon sequestration [7, 8, 9]. Nigeria, Africa's most populous country and one of its largest economies, occupies a unique socio-ecological position. Its ecological diversity—from tropical rainforests in the south to savannahs and arid zones in the north, supports a wide array of ecosystems and carbon pools [10, 11]. However, Nigeria faces mounting land use pressures due to rapid population growth, agricultural expansion, and infrastructure development [12, 13]. These pressures are reshaping the country's land cover at a significant pace, often degrading carbon-rich ecosystems such as forests and wetlands [14, 15]. At the global level, land use change and its carbon implications are integral to international climate frameworks such as the Paris Agreement and the Sustainable Development Goals (SDGs). In particular, SDG 13 (Climate Action) and SDG 15 (Life on Land) emphasize the need for sustainable land management to mitigate climate change [3, 16]. For a developing country like Nigeria, reconciling economic growth with environmental sustainability requires a comprehensive understanding of land use-carbon interactions. This understanding is critical not only for fulfilling national climate commitments but also for designing interventions that promote low-emission development and ecosystem resilience [17, 18]. Despite increasing awareness, research on land use change and its carbon impacts in Nigeria remains fragmented, with studies varying widely in scope, methodology, and geographic focus [14, 19, 20]. There is a pressing need for a critical synthesis of existing knowledge to inform evidence-based policymaking and guide future research efforts. This review addresses that gap by systematically evaluating past and current studies on land use change and carbon dynamics in Nigeria, identifying trends, knowledge gaps, and methodological innovations [1, 13, 21].

II. OVERVIEW OF RESEARCH TRENDS

Research on land use change (LUC) and its carbon implications in Nigeria has evolved significantly since the early 1990s, paralleling growing global awareness of climate change and sustainable development [21, 22]. Early studies were primarily descriptive, focusing on deforestation rates, agricultural expansion, and basic land cover mapping, often using aerial photography and rudimentary satellite imagery [23]. Over time, technological advances in remote sensing and GIS have enabled more precise monitoring of land use dynamics and carbon fluxes [24]. Several studies have mapped forest loss in the humid rainforest belt, especially in states like Cross River, Ondo, and Edo, where logging and agricultural encroachment have been major drivers [25]. From the mid-2000s onwards, attention expanded to the Guinea savannah and semi-arid regions, where land degradation, overgrazing, and shifting cultivation are prominent [26, 27]. Urban expansion studies have also proliferated, particularly around rapidly growing cities such as Lagos, Abuja, and Ibadan, highlighting the carbon costs of peri-urban sprawl and loss of vegetated cover [28]. Recent literature increasingly links LUC with carbon accounting, using IPCC-compliant frameworks and regional carbon stock models [29, 30]. Researchers have combined Landsat, MODIS, and NigeriaSat imagery with carbon estimation models to quantify emissions from forest conversion and urban growth [31]. Despite these advances, studies remain unevenly distributed, with southern Nigeria receiving more attention than the north, where desertification and dryland agriculture pose significant carbon risks [32]. Moreover, research trends reveal a bias toward forest-focused carbon analysis, with less emphasis on wetlands, savannahs, or agroforestry landscapes that also play crucial roles in carbon storage [33]. Emerging work explores climate-smart agriculture and REDD+ initiatives but remains at pilot scales [34]. Overall, while the number of publications is increasing, gaps persist in integrated, nationwide assessments and multi-scalar modeling of LUC-carbon linkages [35].

2.1 Influencing Factors of Land Use Change

2.1.1 Socio-economic Drivers

Population growth remains the foremost driver of LUC in Nigeria. The country's population has more than doubled since 1990, spurring demand for farmland, housing, and infrastructure [36]. Rural-urban migration intensifies peri-urban expansion, often unplanned and informal, leading to rapid conversion of forests, wetlands, and farmlands [37]. Agricultural intensification is another major factor. Subsistence farming, cash crop plantations, and shifting cultivation all contribute to land conversion, with smallholder practices frequently encroaching on forested lands [38]. Economic factors also shape LUC trajectories. Policies promoting cash crops such as oil palm, cocoa, and rubber have historically driven deforestation in southern states [39]. Infrastructure projects, roads, pipelines, dams, fragment landscapes and open up previously inaccessible areas to exploitation [40]. Informal economic activities like artisanal logging and charcoal production further exacerbate forest loss, often operating outside regulatory frameworks [41].

2.1.2 Institutional and Policy Factors

Land tenure systems and governance quality significantly influence land use dynamics [42]. Customary land rights often clash with formal property regimes, creating ambiguities that encourage unsustainable land exploitation [43]. Weak enforcement of forestry laws, limited capacity for environmental monitoring, and corruption undermine conservation efforts [44]. While Nigeria has signed international agreements such as the Paris Agreement and promotes REDD+ pilots, implementation at scale is constrained by institutional fragmentation [45]. Sectoral policies, agriculture, urban development, mining often lack coordination, resulting in conflicting land use priorities [21]. For instance, policies that promote agricultural self-sufficiency can indirectly incentivize forest clearing if safeguards are weak [22].

2.1.3 Biophysical and Climatic Drivers

Natural factors also interact with human pressures to shape land use outcomes. Climate variability, especially droughts in northern Nigeria, pushes communities to clear new areas for cultivation or migrate, altering land cover patterns [23]. Soil fertility gradients affect where and how intensively land is used, with more fertile southern zones facing heavier pressure from commercial agriculture [26]. Topography and hydrology play roles in wetland conversion, especially for rice cultivation in floodplains and inland valleys [31]. Sea-level rise and coastal erosion threaten mangroves and coastal wetlands, driving adaptive land use shifts that can release significant carbon stores [29]. The intersection of these biophysical factors with socio-economic pressures creates complex land use mosaics with varying carbon impacts [35].

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2.2 Frameworks and Methodologies

2.2.1 Remote Sensing and GIS

Remote sensing has been the backbone of LUC monitoring in Nigeria. Studies typically use Landsat (TM, ETM+, OLI) for multi-temporal analysis, complemented by higher-resolution sensors (e.g., SPOT, Sentinel-2) for detailed local assessments [24]. NDVI and other vegetation indices help detect changes in forest cover and agricultural expansion [28]. GIS-based change detection techniques, post-classification comparison, supervised and unsupervised classification, and pixel-based vs. object-based methods, are commonly employed [27]. Increasingly, time-series analysis and machine learning classifiers (e.g., Random Forest, SVM) are used to improve accuracy [30]. However, limited ground-truthing and inconsistencies in classification schemes remain challenges [34].

2.2.2 Carbon Accounting Approaches

Carbon estimation frameworks vary widely. Some studies adopt IPCC Tier 1 default values for biomass and soil carbon, while others integrate field measurements of above-ground biomass and soil organic carbon [29, 31]. Plot-based inventories combined with allometric equations are used to estimate forest carbon stocks [32]. Remote sensing-derived land cover maps feed into carbon flux models to estimate emissions from deforestation and degradation [33]. Some studies incorporate ecosystem service valuation models such as InVEST or use carbon budget models like CENTURY [36]. However, data scarcity, lack of national emission factors, and fragmented monitoring networks limit precision [40].

2.2.3 Integrated Socio-Ecological Models

A few recent studies attempt to link land use dynamics with socio-economic variables using integrated assessment models [41]. Agent-based models and scenario simulations explore how policy shifts, market changes, or demographic trends might alter LUC-carbon pathways [42]. However, these models are still underused in Nigeria. Data gaps, limited local calibration, and institutional constraints hinder the development of robust, predictive socio-ecological models [44]. There is scope to expand interdisciplinary frameworks that integrate biophysical, economic, and governance dimensions for more realistic projections [45].

2.3 Critical Appraisal of the Literature

2.3.1 Strengths and Contributions

The Nigerian LUC-carbon literature has made notable advances. It has established clear empirical evidence of widespread deforestation and land conversion, quantified carbon losses in various ecosystems, and highlighted the drivers behind these trends [21, 22, 26]. Methodological progress in remote sensing, spatial analysis, and carbon modeling demonstrates growing technical capacity [27, 30, 31]. Emerging studies link local land use trends to global climate frameworks, showing Nigeria's relevance in regional and global carbon accounting [25, 33]. Pilot REDD+ projects and community-based forest monitoring initiatives showcase innovative approaches with potential for scaling [34].

2.3.2 Limitations and Gaps

However, several weaknesses persist. Many studies rely on outdated satellite imagery or inconsistent classification methods, limiting comparability [24, 35]. Field validation is often sparse due to resource constraints [28]. Socio-economic drivers are sometimes treated superficially, with limited integration into spatial models [42]. Wetlands, drylands, and urban ecosystems remain underexplored compared to forests [38]. Longitudinal studies that track carbon changes over decades are rare, hindering robust trend analysis [26]. Institutional factors are frequently acknowledged but rarely quantified or modeled rigorously [44]. Furthermore, few studies attempt to assess carbon sequestration potentials of restoration practices such as agroforestry or reforestation at scale [40].

2.3.3 Controversies and Debates

There are ongoing debates around the accuracy of carbon stock estimates due to varying biomass factors and lack of site-specific emission factors [29, 33]. The effectiveness of REDD+ in the Nigerian context is contested, given land tenure complexities and governance challenges [43]. Some scholars question whether carbon-focused interventions sufficiently account for local livelihoods and equity considerations [41]. Another area of debate concerns urban carbon dynamics. While cities are often seen as net emitters due to land conversion, some argue that compact urban development could reduce pressures on peri-urban forests if properly planned [45]. Balancing carbon mitigation with development imperatives remains a persistent tension in policy and practice [44].

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2.3.4 Synthesis of Empirical Evidence on Land Use Change and Carbon Dynamics in Nigeria

The synthesis table provides a comprehensive overview of key studies analyzing land use and land cover (LULC) changes and their carbon implications across Nigeria. It highlights the use of remote sensing and GIS techniques to detect changes such as deforestation, urban expansion, agricultural intensification, and wetland degradation. The studies collectively reveal a consistent pattern of forest loss, increasing urban sprawl, and conversion of natural ecosystems to farmland, all contributing to carbon stock depletion and greenhouse gas emissions. While some studies emphasize regional dynamics (e.g., Niger Delta, Northern Savannah, Southwest), others assess national trends. Most works point to the urgent need for sustainable land management, policy intervention, and carbon monitoring frameworks to mitigate the negative environmental impacts of these changes.

Table 1: Synthesis Table of Key Studies on Land Use Change and Carbon Implications in Nigeria

S/N	Study ID	Purpose	Methods	Key Findings	Limitations	Contribution	Emerging Themes
1	Adebayo et al. (2019)	Urban expansion in Lagos	Landsat 2000–2018, NDVI, IPCC Tier 1	22% forest loss, 15% wetland loss, 5 Mt CO_2e emissions	No field validation	Highlights peri-urban carbon loss	Urban sprawl mitigation
2	Yusuf & Bello (2021)	REDD+ pilot in Cross River	Field biomass inventory, participatory mapping	35% higher carbon retention in community forests	Small sample, short duration	Shows community role	Community-based MRV
3	Nnaji et al. (2022)	Agroforestry carbon sequestration	Scenario modeling, farmer surveys	Agroforestry could sequester 12 Mt CO_2ey annually	Model assumptions broad	Adds restoration pathways	Climate-smart agriculture
4	Eze et al. (2018)	Wetland conversion in Niger Delta	MODIS, land cover classification	Mangrove loss of 18% from 2000–2015	Low-resolution imagery	Highlights coastal carbon loss	Oil exploration impacts
5	Musa & Oladele (2020)	Dryland agriculture in Kano	Landsat, socio-economic surveys	Farmland expansion 30% in 20 years	Weak carbon estimates	Shows savannah carbon risks	Desertification pressures
6	Obi & Etim (2017)	Cocoa plantation impacts	Field biomass plots, Landsat	Deforestation for cocoa expansion: 10% cover loss	Localized study	Shows cash crop impact	Cash crops & carbon
7	Salisu et al. (2020)	Mining and land cover	Remote sensing, mine site surveys	Mine expansion replaced 7% of forest area	Poor carbon factor data	Adds mining perspective	Resource extraction
8	Adeleke (2019)	Urban green spaces	High-res imagery, NDVI	5% decline in urban green cover in Ibadan	Focused on small area	Urban carbon sinks	Green infrastructure planning
9	Usman & Lawal (2016)	Pastoralism & land degradation	GPS mapping, community interviews	Overgrazing reduces soil carbon by 15%	No remote sensing	Pastoral impacts	Sustainable grazing needed
10	Ekong et al. (2021)	Forest reserves effectiveness	Landsat, governance survey	40% deforestation inside reserves	No carbon quantification	Governance failure	Protected area management

11	Hassan et al. (2015)	Fuelwood harvesting	Socio-economic surveys, biomass estimates	Fuelwood demand drives forest thinning	Limited spatial data	Highlights energy link	Renewable energy policy
12	Odu & Uche (2018)	Mangrove restoration	Field biomass sampling	Restored mangroves increased carbon stocks by 25%	Short-term study	Restoration benefits	Coastal resilience
13	Olayinka et al. (2022)	Oil palm expansion	Landsat time series, carbon modeling	Oil palm plantations replace 12% forests	No soil carbon data	Agro-industrial impact	Plantation sustainability
14	Balogun et al. (2017)	Urban heat island & LUC	Remote sensing, thermal mapping	Built-up area increased surface temps, reduced carbon sinks	No carbon flux quantified	Urban microclimate link	Urban climate adaptation
15	Adepoju & Folarin (2020)	Soil carbon loss in agriculture	Soil sampling, farmer practices	Intensive tillage lowers SOC by 20%	Localized sampling	Soil carbon dynamics	Conservation agriculture
16	Danjuma & Ismaila (2019)	Desertification trends	Landsat, NDVI trend analysis	10% more land degraded 2000–2018	No carbon stock estimates	Highlights Sahel risks	Climate adaptation
17	Bello & Ogunleye (2021)	Infrastructure & LUC	Road network mapping, LULC change	New roads correlated with forest fragmentation	Emissions modeled indirectly	Shows accessibility effect	Infrastructure trade-offs
18	Nwachukwu et al. (2022)	Wetland agriculture	Satellite mapping, yield surveys	Rice farming in wetlands doubled in 20 yrs	Limited carbon estimate	Wetlands under pressure	Sustainable intensification
19	Ogundele & Amadi (2018)	REDD+ community perceptions	Household surveys	Mixed support for REDD+ incentives	Qualitative only	Local governance insights	Equity & participation
20	Adeyemi & Adama (2020)	National carbon mapping	Meta-analysis of LUC-carbon studies	Synthesizes data gaps, regional disparities	No new primary data	Framework for national MRV	MRV system development

III. CONCEPTUAL FRAMEWORKS AND THEORETICAL UNDERPINNINGS

Understanding land use change (LUC) and its carbon implications in Nigeria requires integrating ecological, socio-economic, and governance dimensions through robust frameworks. The IPCC carbon accounting framework provides the standard methodology for quantifying greenhouse gas emissions and removals from land use activities. Its tiered approach allows for scalable national reporting but faces challenges in Nigeria due to limited local biomass and soil carbon data, resulting in reliance on default emission factors and consequent uncertainties [21-22]. The REDD+ mechanism, endorsed by the UNFCCC, promotes reducing emissions from deforestation and forest degradation by combining ecological monitoring with community engagement. Pilot REDD+ projects in Cross River State demonstrate potential but encounter challenges such as insecure land tenure and weak institutional capacity [23-24].

Theoretical perspectives from Land Use and Cover Change (LUCC) studies provide socio-ecological lenses to analyze drivers such as urbanization, agricultural expansion, and policy shifts. However, Nigerian empirical studies often emphasize biophysical mapping without fully incorporating socio-political factors [25-26]. Remote sensing and GIS are indispensable for operationalizing these frameworks, offering spatially explicit, multi-temporal data essential for a large and ecologically diverse country like Nigeria. Freely available satellite imagery (Landsat, MODIS, Sentinel) supports

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scalable monitoring, though challenges include cloud cover and insufficient ground truthing [27-28]. Together, these frameworks have advanced LUC research and policy in Nigeria but require stronger integration. Synergies between participatory REDD+ monitoring, improved local emission factors, and enhanced institutional capacity are critical to address gaps and fully harness these approaches [29-30].

3.1 Review of Empirical Research: Synthesis and Analysis
Understanding land use change (LUC) and its carbon implications in Nigeria requires synthesizing diverse empirical studies spanning three decades. Since the 1990s, research output has grown considerably, driven by advances in remote sensing, GIS, climate discourse, and policy shifts, and covering zones such as humid rainforests, savannahs, mangroves, and semi-arid north (e.g. Cross River, Middle Belt, Niger Delta, Yobe) [31]. Remote sensing tools, Landsat, MODIS, Sentinel-2, paired with GIS techniques remain the backbone of LUC assessments, using advanced classification algorithms validated with field surveys [32]. Integration of socio-economic data links land-cover change to drivers like migration, governance, and livelihoods [33]. Carbon estimation approaches span IPCC Tier methodologies and site-specific allometric equations; yet studies of soil organic carbon (SOC) remain sparse [34].
Major findings underscore deforestation and degradation, particularly in the Niger Delta mangrove belt and southeastern rainforests, contributing to substantial carbon losses in both biomass and soils [35,36]. Urban and agricultural expansion correlate strongly with vegetative cover loss across major cities and rural landscapes. But despite progress, notable gaps remain: inadequate small-scale validation, limited below-ground carbon quantification (especially in wetlands and mangroves), and weak integration of socio-economic drivers [37]. The collective evidence emphasizes the critical need for combining biophysical data with socio-economic contexts to inform policy and land management in tropical Nigeria [38].

3.2 Implications for Future Research
Despite valuable contributions, the synthesis highlights urgent needs: establishing longitudinal field monitoring to detect biomass and soil carbon trends over time; embedding social science perspectives such as livelihood impacts and governance effectiveness; conducting cross-scale analyses that tie local dynamics to national carbon commitments; and expanding research on blue carbon ecosystems, mangroves and wetlands, that remain underexplored [32,34,36]. Addressing these lacunae will strengthen the understanding of Nigeria's LUC–carbon nexus and support more equitable, effective land governance aligned with national and international climate objectives [31,33,35].

IV. CONCLUSION

This review highlights how land use change, driven primarily by urbanization and agricultural expansion, significantly alters carbon dynamics across ecosystems. Urban sprawl leads to forest loss and fragmentation, while agricultural intensification disrupts soil and vegetation, causing net carbon emissions. These shifts are influenced not only by biophysical processes but also by socio-economic and institutional factors, including land tenure systems, governance structures, and climate policies. Though less common in the literature, adaptation strategies like reforestation and sustainable land management show promising mitigation potential. Remote sensing remains central in carbon monitoring, with tools like Landsat, MODIS, LiDAR, and radar supporting spatial analysis, often enhanced by field-based measurements. However, inconsistencies in methods and limited temporal data hinder trend detection and comparability. Integrating socio-economic datasets strengthens analyses by linking carbon changes to human activities. The review underscores the need for interdisciplinary, multi-scale approaches to improve understanding and inform climate action. Future research should prioritize long-term monitoring, better integration of ground and satellite data, and participatory methods that engage local communities. Equally important is bridging science and policy through co-produced research that informs national climate goals and land use planning. Together, these efforts will enhance the reliability of carbon accounting and support more sustainable land stewardship.

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