International Journal of Environment and Climate Change

Volume 14, Issue 7, Page 222-233, 2024; Article no.IJECC.119061
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Remote Sensing Methods and GIS Approaches for Carbon Sequestration Measurement: A General Review

Kossivi Fabrice Dossa [a,b,c*] and Yann Emmanuel Miassi [a,b]

[a] Faculty of Forestry, Geography and Geomatics, Laval University, Quebec, QC G1V 0A6, Canada.
[b] Department of Research Project, Action-Research for Sustainable Development NGO, Cotonou-03296, Benin.
[c] Department of Agricultural Economics, Faculty of Agriculture, University of Nigeria, Nsukka-041006, Nigeria.

Authors' contributions

This work was carried out in collaboration between both authors. Author KFD conceptualized the research work, did the software, investigation, did data curation, supervised the study, did the project administration, did the funding acquisition. Authors KFD and YEM did the methodology, validation, did formal analysis, resources, wrote original draft preparation, reviewed and edited the manuscript, visualization. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i74265

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/119061

Systematic Review Article

Received: 23/04/2024
Accepted: 28/06/2024
Published: 01/07/2024

ABSTRACT

Geospatial technologies like Remote Sensing (RS) and Geographic Information Systems (GIS) provide a platform for swiftly evaluating terrestrial Carbon Stock (CS) across extensive regions. Employing an integrated RS-GIS method for estimating Above-Ground Biomass (AGB) and precise carbon management emerges as a timely and economical strategy for implementing effective management plans on a localized and regional level. This study reviews different RS-related techniques utilized in CS assessment, particularly in arid lands, shedding light on the challenges,

**Corresponding author: E-mail: Fabdossa@gmail.com;*

Cite as: *Dossa, Kossivi Fabrice, and Yann Emmanuel Miassi. 2024. "Remote Sensing Methods and GIS Approaches for Carbon Sequestration Measurement: A General Review". International Journal of Environment and Climate Change 14 (7):222-33. https://doi.org/10.9734/ijecc/2024/v14i74265.*

opportunities, and future trends associated with the process. As global warming poses adverse impacts on major ecosystems through temperature and precipitation changes, professionals have a call to develop evidence-based interventions to mitigate them. Carbon sequestration involves harnessing and storing carbon stocks from the atmosphere to minimize the adverse effects of climate change. The review explores the effectiveness of integrating remote sensing and GIS methodologies in quantifying carbon sequestration within agroforestry landscapes. In addition, this review also assesses the traditional methods, including their limitations, and deeply delves into recent techniques, emphasizing key remote sensing (RS) variables for biophysical predictions. This study showcases the efficacy of geospatial technologies in evaluating terrestrial carbon stock, particularly in arid regions. The study reviews diverse techniques and sensors, like optical Radio Detection and Ranging (RADAR), and Light Detection and Ranging (LiDAR), extensively employed for above-ground biomass (AGB) estimation and carbon stock assessment with RS data, introducing and discussing new methods. Existing literature was examined to present knowledge and evidence on the effectiveness of these technologies in carbon sequestration. The key findings of this review will inform future research and integration of technology, policy formulation, and carbon sequestration management to mitigate the impacts of climate change.

Keywords: Remote sensing; geospatial technologies; carbon sequestration; agroforestry landscape; carbon stock assessment.

1. INTRODUCTION

1.1 Background and Context

Carbon sequestration is capturing, harnessing, and storing carbon dioxide from the atmosphere to reduce its contribution to global warming [1]. In the wake of climate change and the severe effects on world temperature and water resources, experts can employ natural and artificial techniques such as afforestation and carbon capture technologies to support carbon sequestration [2]. Quantifying carbon sequestration is an exciting technology that attracts research to ensure sustainable climate change mitigation and land resource management [3]. According to Hammad et al. [4], agricultural landscapes successfully remove considerable greenhouse gases from the surrounding environment by combining croplands and bushes for carbon absorption.

Satellite imagery collects information on plants, land coverage, and other surface operations on Earth using drones and aerial photography [5,6,7]. So, the information is analyzed and interpreted using Geographic Information System (GIS) technology to enable well-informed decision-making [8]. Because of their superior ecological study skills, professionals use remote sensors and GIS to evaluate and measure carbon retention in agricultural ecosystems [9]. Plant types, nutritional status, and geographical distribution are all determined using satellite photography [10].

Carbon sequestration assessments are more accurate and efficient when remote sensing is used with Geographic Information System (GIS) techniques [11]. Researchers can calculate and visualize the carbon dynamics within agroforestry systems thanks to this approach, which also helps quantify biomass and estimate carbon stocks in soil and trees [12]. GIS also considers ecological features such as geography and climate to comprehend factors affecting carbon sequestration rates. Informed decisions about sustainable land use are also made easier by this integration for policymakers and land managers [13].

Monitoring of temporal changes in carbon sequestration, deforestation, vegetation growth, and afforestation activities is made possible by the integration of remote sensing and Geographic Information System (GIS) techniques [14]. By evaluating the long-term viability of agroforestry techniques and offering spatial data for ideal placements and carbon sequestration, GIS is essential to the mitigation of climate change [15]. For climate change resilience and mitigation decisions, this integration improves adaptive environmental management strategies and real-time monitoring.

In this review we present some of the latest technologies in carbon assessment in agricultural landscapes. The introductory part focuses on contextualizing the research within the scope of climate change mitigation by underscoring the significance of carbon sequestration. It also analyzes agroforestry landscapes as the primary contributors to carbon sequestration in the context of sensing and GIS methodologies.

1.2 Statement of the Problem

With the ever-rising global temperatures and adverse weather patterns, Climate change, is causing severe humanitarian and ecological consequences due to the emissions of carbon and toxic gases into the atmosphere. There must be sufficient research and knowledge on the subject matter to inform evidence-based interventions toward mitigating climate change effects. There needs to be more knowledge between what we know and what we ought to know, raising more curiosity on the need for continuous research. Through that lens, this study seeks to address the critical gap in current research concerning the quantification of carbon sequestration within agroforestry landscapes. Existing studies in this area need more precision and spatial analysis on carbon sequestration. Hence, they fail to capture the dynamics of carbon stocking and storage between crops, trees, and soil. Moreover, the need to integrate new technologies such as remote sensing and GIS approaches also hinders the development of evidence-based frameworks for efficient and accurate assessment of carbon sequestration within the agroforestry landscapes. Presenting evidence in this area will also help experts, professionals, and policymakers understand carbon sequestration dynamics in agroforestry landscapes and make informed land-use decisions on bridging the gaps to mitigate the impacts of climate change.

2. PURPOSE OF THE REVIEW

This study proposes to investigate, evaluate, and report on the role of remote sensing and GIS approaches in quantifying carbon sequestration within agroforestry landscape settings. However, using remote sensing and GIS technology, the project seeks to improve the accuracy and efficiency of carbon sequestration processes in agroforestry landscapes [16]. This will support land-use planning and sustainable mitigation of climate change. Informed decisions about land use and environmental compliance are facilitated by the study's support for the development of scientific data on the integration of remote sensing and GIS in managing carbon sequestration in agroforestry landscapes. Materials and Methods.

To show a strong structure, the study employed systematic literature review approaches [17]. Initially, a study topic was chosen, and then relevant materials, including research papers, critiques, short remarks, discussions, and reviews, were retrieved by searching academic databases such as Google Scholar, Scopus Index Journals, Emerald, Elsevier Science Direct, Springer, and Web of Science. From a total of 200 articles, only 40 were selected based on their relevance and significance to the topic of this review.

To enhance the caliber and openness of systematic review and meta-analysis reporting, articles are screened using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which was developed in 2009 and revised in 2020 [18]. Hence, it helps raise the bar for reporting standards in a variety of fields by providing authors with an organized framework for communicating and duplicating systematic reviews.

Despite its early phases, the research effort did not apply strict criteria for exclusion, enabling a thorough examination free from regional differences [19]. It featured works with a variety of approaches, such as books, student theses, and empirical works like original investigations. Newspaper and magazine articles, which are non-empirical sources, were not included. Undergraduate theses were added to counteract publication bias because peer-reviewed publications typically give preference to research with quantitatively relevant outcomes.

To guarantee the most recent data, the study only included English-language publications that had been published in the previous year. The Joanna Briggs Institute's Critical Appraisal Checklist for Analytical Cross-Sectional Studies, the Critical Appraisal Skills Program's Qualitative Checklist, and the Mixed Methods Appraisal Tool (MMAT) for quantitative, qualitative, and mixed-methods studies were among the checklists examined by various scholars and used for quality evaluation because they were specific to the study layout.

3. RESULTS

The efficiency of carbon sequestration technologies is discussed in this part, along with an emphasis on the main features and parts of the systems and how artificial intelligence (AI) can be used to improve their performance, optimize operational parameters, and enhance real-time monitoring and control for better adaptability and reduced environmental impact.

3.1 Technologies Used in Quantifying Carbon Sequestration

Remote sensing: To assess carbon sequestration, Vilar et al. [20] emphasize the use of remote sensing technologies such as satellite photography and aerial surveys. These technologies offer up-to-date data on variations in land cover, biomass, and vegetation health [21]. Nonetheless, experts may track and gauge carbon stocks in expansive agroforestry systems and forest landscapes thanks to satellite-based remote sensing [22]. LiDAR, or light detection and ranging, is a useful cutting-edge technology that improves measurement precision.

Satellite photography, aerial surveys, and LiDAR provide crucial land cover, biomass, and vegetation health data for carbon sequestration assessment. These technologies have drawbacks include expensive setup and operating expenses, especially with high-resolution sensors and complex systems like LiDAR. Cloud cover and other atmospheric factors may obscure satellite and aerial images, causing data collecting delays or gaps. Satellites' short return durations may restrict these technologies' temporal resolution for monitoring fast environmental changes [23].

Remote sensing data is complicated and needs sophisticated processing and analysis, which may be difficult in locations with limited technological resources. Spatial resolution limits may limit the data's value for comprehensive local analysis, and reliance on sunlight for lighting may alter data collection time and consistency. Remote sensing's wide advantages in environmental monitoring frequently exceed its downsides, especially when combined with other data collection methods [24].

Geographic information system (GIS): GIS technology is a crucial tool for quantifying carbon sequestration, as it integrates diverse spatial datasets like climate patterns, topography, and land cover, according to Ambaw et al. [25]. Hence, Lourenço et al. [22] say it helps scientists assess land use effects on carbon dynamics and identify optimal locations for afforestation or reforestation initiatives, enhancing the reliability and accuracy of carbon sequestration efforts. GIS technology plays a crucial role in measuring carbon sequestration by combining various geographical information and enhancing the precision of evaluating the impact of land use on carbon dynamics. However, it does possess significant drawbacks. A major constraint is its reliance on the quality and accessibility of input data; flaws in the source data might result in errors in the output, which can impact decision-making procedures. In addition, Geographic Information Systems (GIS) need significant computing resources and technical proficiency to efficiently handle and analyze extensive information. The intricate nature of this may provide difficulties in terms of accessibility, especially in settings with low resources, which might impede the general acceptance and efficient use of global carbon management measures [26].

Eddy covariance towers: The Eddy Covariance method, pivotal in atmospheric sciences for measuring gas exchanges between ecosystems and the atmosphere, began taking shape in the early 20th century, rooted in the theoretical work on turbulent diffusion by Sir Geoffrey Ingram Taylor in 1915 [27]. It advanced significantly in the mid-20th century with the development of instruments like sonic anemometers, which could accurately measure atmospheric turbulence. The practical application of these theories and tools led to the widespread use of Eddy Covariance Towers by the late 20th century [28]. These towers, equipped with various sensors, have become essential in global networks for studying climate change, carbon cycles, and ecosystem dynamics, continuing to evolve with technological advances in sensors and data analytics. Berg et al. [29] and Sun et al. [27] have highlighted the use of eddy covariance towers, sensor-equipped ground-based equipment, for measuring gas exchanges, including carbon dioxide, and their potential for carbon sequestration [29]. These towers are strategically placed in agriculture fields and woodlands to deliver accurate, real-time carbon fluxes, enabling scientists to compute net carbon content and seasonal ecosystem fluctuations [27]. The accuracy in carbon fluxes and seasonal changes helps professionals plan and respond to environmental changes [28]. However, Eddy Covariance Towers may face limitations due to their high cost of operation and technological intricacy, necessitating ongoing maintenance and calibration to ensure precise measurements. Furthermore, the efficacy of these devices relies on consistent meteorological conditions, since significant fluctuations in wind and the absence of turbulence may undermine the accuracy of the gathered data [30].

Carbon monitoring systems and models: Currently, carbon monitoring systems are computational technologies and AI algorithms-driven [31]. These technologies help simulate and project carbon stocks and variations in various landscapes to mitigate the impact of climate change. Burba [28] confirms that dynamic global vegetation models (DGVMs) are among the most sophisticated ecosystem tools for simulating responses to changing environmental conditions and human activities. Scientists employ DGVMs to explore various environmental scenarios and predict the impact of different variables on carbon sequestration [27]. Experts can create more efficient mitigation measures for climate change by having a better awareness of the other factors that impact carbon capture and storage.

Optimizing carbon sequestration with remote sensing and GIS: Wang et al. [32] discovered that by leveraging cutting-edge technology, including satellite imaging and aerial data, remote sensing and GIS may maximize carbon sequestration [16]. By precisely identifying the best sites for planting trees or regeneration activities to optimize carbon sequestration possibilities, this improves the efficacy and precision of carbon evaluations [33].

3.2 Case Studies for Successful Implementation of Remote Sensing and GIS

GIS and remote sensing technologies were successfully used by the Brazilian Amazon Rainforest Land Use Changes monitoring project to track and assess land use changes (see Fig. 1). Over time, high-resolution images were gathered using Landsat Sentinel satellite imagery [34]. Different land use classifications, such as agricultural land, deforested areas, and protected reserves, were also classified using GIS tools, satellite data analysis, and land cover classification algorithms.

GIS and remote sensing technologies were effectively employed by Singapore's Urban Planning and Infrastructure Development team to enhance infrastructure design and promote equitable urban development. However, they improved the effectiveness and precision of urban development activities by using high-resolution LiDAR and aerial photography to construct precise three-dimensional models of the urban terrain. Urban areas became more robust and livable because of this strategy.

Land cover changes were identified by using remote sensing methods to track conservation initiatives and deforestation trends [35]. Analysis of data and representation using GIS techniques revealed areas susceptible to land-use changes and rapid deforestation. The purpose of this material was to promote global cooperation and increase public awareness about the preservation of the Amazon rainforest.

Challenges faced in adopting remote sensing and GIS: The difficulties of implementing GIS and remote sensing in carbon sequestration projects are emphasized by Qiu et al. [1]. These difficulties include the expensive starting point, high skill, experience, and training needs, as well as the need to address interoperability and improve data accuracy. Due to the need to balance computing needs with high-resolution data, these problems can be especially difficult for smaller groups or areas with low funding.

3.3 Climate Change Impacts and Mitigation Strategies

Climate change effects on carbon stocks: By upsetting the equilibrium between carbon sources and sinks, climate change severely depletes ecosystems' carbon reserves [32]. Degradation rates, vegetation development, and the structure of soil carbon are significantly impacted by extreme weather patterns, variations in precipitation, and humidity [35]. Warmer temperatures, for instance, stimulate the growth of bacteria and quicken the organic matter's breakdown, releasing stored carbon into the sky. The spatial distribution and health of the vegetation are also impacted by these changes, which shape the capability for sequestering carbon.

Role of carbon sequestration in climate change mitigation: Carbon sequestration is the process of taking carbon dioxide out of the atmosphere and storing it in soil and forest reservoirs, according to Xaverius et al. [9]. Forest loss and forestry combined with environmentally friendly land use improve carbon sequestration and the net decrease in carbon dioxide emissions by an equal amount [32]. These sequestration activities mitigate the adverse effects of climate change by lowering atmospheric carbon concentrations, a critical trigger of global warming.

Fig. 1. tracking land use and deforestation in the Brazilian Amazon [34]

4. DISCUSSION

The study critically examines the integration of advanced remote sensing and GIS technologies in carbon sequestration in agroforestry landscapes. It intends to assess detailed information on spatial distribution, vegetation health, and land cover by leveraging GIS and remote sensing using aerial data and satellite imagery. It is essential to highlight the synergies between remote sensing, GIS, and other technologies to enhance understanding of significant variables around carbon sequestration in soil and trees in the agroforestry landscapes. The second significant aspect forming the backbone of this study is the goal of contributing to climate change mitigation through sustainable land-use planning. Integrating modern technologies such as remote sensing and GIS is critical to more clarity in climate change mitigation strategies and decision-making [2]. Still, conducting a detailed spatial analysis of carbon sequestration puts the study in a position to inform environmental professionals, policymakers, and land managers to make informed decisions on optimizing agroforestry practices [3].

Overview of traditional carbon sequestration approaches: Based on the assertions of Seitz et al. [36], traditional carbon sequestration has been centered around enhancing the role of natural and artificial forests through afforestation and cover cropping activities. Afforestation has significantly sequestrated carbon dioxide by capturing and storing carbon dioxide from the atmosphere [4]. Due to their vast biomass, it is imperative to note that forests have a high capacity to store carbon in trees, crops, and soil for a long time [37]. In that context, environmental experts have prioritized afforestation activities by preserving forests and planting new trees to enhance high-carbon storage. In that regard, afforestation is the most prioritized traditional way of sequestrating and sinking carbon by increasing biomass. These traditional activities have been instrumental in controlling the effects of climate change since they reduce carbon emissions.

Apart from forestry, cover cropping, and no-till farming in have been used as traditional ways of soil carbon sequestration because they help maintain ground cover by minimizing soil degradation [16]. By minimizing soil disturbance, cover cropping and no-till farming foster favorable conditions for carbon accumulation [33].

Challenges of traditional carbon sequestration methods: Due to their restricted spatial resolution and emphasis on certain ecosystems, traditional carbon sequestration techniques, although helpful in reducing the effects of climate change, have drawbacks [38]. Since these traditional carbon storage approaches could only be used to sequestrate carbon in specific areas, they exude gaps in understanding carbon storage dynamics across various landscapes. As human activities escalate is evident that traditional carbon storage methods cannot combat the effects of climate change efficiently and effectively [39]. Since emerging technologies like remote sensing and GIS can gather data in real time and produce current results for well-informed environmental decisions, research on these technologies is essential to increasing the accuracy and scalability of carbon sequestration estimates [40].

According to Hou et al. [41], obstacles to afforestation, the process of planting new trees in formerly unforested areas, include competition from agriculture and a shortage of land due to urban expansion. Water shortage, biodiversity loss, and soil nutrient loss can result from improper tree selection [42]. Pests, erratic weather patterns, and wildfires are some of the climate change disturbances that reduce its efficiency in sequestering carbon [43].

Growing crop varieties during non-planting seasons to prevent nutrient loss and improve soil is known as "cover cropping," a classic way of storing carbon in the soil. Its reliance on crop types, selection, and climate patterns, however, has constraints [44]. The viability could need to be improved in regions with limited water supplies, and illnesses and pests could make it less successful [45]. According to Huang et al. [46], cover crops have a limited ability to sequester carbon because the carbon they store escapes into the atmosphere during decomposition.

Smart carbon sequestration methods: Precision farming is one example of a smart carbon sequestration strategy that uses cutting-edge technology to maximize carbon capture and storage [25]. Drones, sensors, and satellite photography are used in these techniques to measure and control carbon in agricultural landscapes, supporting efforts to mitigate climate change [47]. To help farmers maximize fertilization and cover cropping, they also track vegetation growth, soil health, and carbon flux [48]. Precision agriculture driven by data maximizes the potential for sequestering carbon while improving the efficiency of carbon storage and supporting sustainable farming practices [49].

A clever method of sequestering energy from biomass, such as plant matter and agricultural leftovers, is carbon capture and storage (BECCS) [37]. According to Lizzaga et al. [10], BECCS is a renewable energy source that aids in removing carbon dioxide from the environment. This approach complements broader ecological strategies; programs for afforestation and reforestation can regulate carbon stocks by utilizing GIS mapping and machine learning technology [32]. Enhancing carbon sequestration for sustainable land use and mitigating climate change can be achieved by combining these technologies with ecological concepts [35].

Gaps and opportunities in current research: Technology-driven strategies to enhance land use decision-making and mitigate the effects of climate change are the main focus of research on carbon sequestration and climate change. Research emphasizes how trees act as carbon sinks and how to balance the rates of afforestation and deforestation [11]. Additionally, they look at how well various forest types can sequester carbon and how susceptible ecosystems are to climate change, especially in light of shifting patterns of temperature and rainfall.

To improve carbon sequestration and agrarian efficiency, studies are looking into carbon sequestration in grasslands, wetlands, and agricultural areas. These studies concentrate on sustainable land management techniques including cover crops and agroforestry [20]. Standardizing carbon sequestration approaches across diverse ecosystems is essential to building a knowledge base for reliability and comparability assessments in agroforestry landscapes.

A thorough examination of the many agroforestry interacting techniques related to carbon dynamics is lacking in the current studies. Despite some individual studies investigating alley cropping, afforestation, or silvopastoral systems, there still needs to be a gap in reconciling research to assess the combined impact of various agroforestry practices on carbon sequestration [22].

Since studies frequently concentrate on localized initiatives, leaving a vacuum in scalability for bigger regions, experts must investigate the capacity for expansion of remote sensing and GIS approaches for carbon sequestration evaluations in agroforestry ecosystems [8].

GIS and remote sensing technologies are used in the carbon sequestration project to improve scientific knowledge about sustainable land management techniques. Professionals now have the chance to create and improve cutting-edge technology (UAVs) [13]. To assess carbon sequestration techniques, researchers might establish multidisciplinary partnerships and collaborative efforts that integrate ecological research with economics, social sciences, and policy studies. This will assist in developing economically and environmentally sound practices for farmers and landowners [14]. Longitudinal studies that concentrate on alterations in carbon stock patterns, ecological services, and ecological diversity can be used to investigate the long-term effects of carbon stocking techniques in agroforestry landscapes [50]. This will enhance comprehension of the durability and long-term viability of agricultural forests as carbon sinks and assess the efficacy of policies and incentives.

5. CONCLUSIONS

Climate change poses severe challenges to all ecosystems due to changes in world temperature, precipitation patterns, and unpredictable climate events. Major human activities such as cutting down forests, industrialization, and burning fossil fuels contribute to excessive carbon emissions into the atmosphere. Traditional methods such as cover cropping and afforestation have been implemented to reduce carbon stocks and mitigate the effects of climate change. However, serious gaps have yet to be discovered in these approaches. Hence, it calls for technology-driven approaches to ensure precise, accurate, and real-time decision-making. Due to climate change impacts on agroforestry and other ecosystems, remote sensing and GIS technologies enhance carbon sequestration processes by ensuring real-time data collection and decision-making. Professionals must strengthen research in this area to present more efficiency in the effective use of technology to enhance carbon sequestration activities in the agroforestry landscape.

6. FUTURE DIRECTIONS AND RECOMMENDATIONS

To increase precision and effectiveness, the study of carbon sequestration in agricultural landscapes must incorporate Artificial Intelligence (AI) and Machine Learning (ML). Combining AI and ML technologies will support the automation of data analysis, improve remote sensing data interpretation, and refine predictive models. Incorporating machine learning algorithms will also help researchers develop more sophisticated tools for mapping and monitoring carbon stocks, leading to more nuanced insights into the dynamics of agroforestry systems.

Dynamic modeling of carbon flux: Future carbon management research should also emphasize creating and integrating dynamic models to account for temporal variations in carbon fluxes within agroforestry landscapes. Dynamic modeling of carbon fluxes will increase efficiency by enhancing real-time data from climate variables, remote sensing technologies, and land-use changes. In turn, this will improve the accuracy of carbon sequestration. These modeling techniques enhance understanding of the long-term effects of carbon stocks and short-term disturbances to create adaptive and resilient land management strategies.

Qualification of Co-benefits of Trade-offs: Focusing on co-benefits and trade-offs is another critical aspect of future research because it will highlight major carbon sequestration practices in agroforestry landscapes. Professionals must channel their focus on practices that influence carbon stocks and other ecosystem services, such as socioeconomic welfare and agricultural productivity. Presenting knowledge and evidence will influence decision-making by highlighting the benefits and trade-offs in various carbon sequestration strategies.

Development of decision support tools: Future research must also be directed towards creating user-friendly decision support tools, especially by integrating GIS and remote sensing for policymakers, land managers, and practitioners. Modern tools are critical for actionable insights and informed decision-making by stakeholders toward optimizing carbon sequestration land-use practices. At the same time, decision-making support tools could incorporate scenario analysis, allowing users to explore the potential outcomes of different management strategies under varying climate and land-use scenarios.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during the writing or editing of the manuscript.

DATA AVAILABILITY STATEMENT

The data used in the present study are available on request from the corresponding author.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Qiu Z, Feng Z, Song Y, Li M, Zhang P. Carbon sequestration potential of forest vegetation in China from 2003 to 2050: Predicting Forest vegetation growth based on climate and the environment. Journal of Cleaner Production. 2020;252:119715. Available:https://www.sciencedirect.com/science/article/pii/S095965261934585
2. Lessmann M, Ros GH, Young MD, de Vries W. Global variation in soil carbon sequestration potential through improved cropland management. Global Change Biology. 2022;28(3):1162-1177. Available:https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.15954
3. Arehart JH, Nelson WS, Srubar III WV. On the theoretical carbon storage and carbon sequestration potential of hempcrete. Journal of Cleaner Production. 2020;266:121846. Available:https://www.sciencedirect.com/science/article/pii/S095965262031893X
4. Hammad HM, Nauman HMF, Abbas F, Ahmad A, Bakhat HF, Saeed S, Cerdà A. Carbon sequestration potential and soil characteristics of various land use systems in arid region. Journal of environmental management. 2020;264:110254. Available:https://www.sciencedirect.com/science/article/pii/S0301479720301894
5. Wengert M, Piepho HP, Astor T, Graß R, Wijesingha J, Wachendorf M. Assessing spatial variability of barley whole crop biomass yield and leaf area index in silvoarable agroforestry systems using UAV-borne remote sensing. Remote Sensing. 2021;13(14):2751. Available:https://www.mdpi.com/2072-4292/13/14/2751
6. Rizvi RH, Newaj R, Chaturvedi OP, Prasad R, Handa AK, Alam B. Carbon sequestration and CO 2 absorption by agroforestry systems: An assessment for Central Plateau and Hill region of India. Journal of Earth System Science. 2019 Apr;128(3):56.
7. Banerjee S, Palit D. Application of geospatial technology for agroforestry management. InAgroforestry for Carbon and Ecosystem Management 2024 Jan 1 (pp. 375-383). Academic Press.
8. Bindu G, Rajan P, Jishnu E S, Joseph K A. Carbon stock assessment of mangroves using remote sensing and geographic information system. The Egyptian Journal of Remote Sensing and Space Science. 2020;23(1):1-9. Available:https://www.sciencedirect.com/science/article/pii/S1110982317303861
9. Xaverius F, Loppies SHD, Siregar K, Vincēviča-Gaile Z, Adinurani PG. Geographic Information system of primary carbon deposit of mangrove forest in Merauke District, Indonesia. In E3S Web of Conferences. 2020;190:00011. EDP Sciences. Available:https://www.e3sconferences.org/articles/e3sconf/abs/2020/50/e3sconf_icorer2020_00011/e3sconf_icorer2020_00011.html
10. Lizaga I, Latorre B, Gaspar L, Ramos MC, Navas A. Remote sensing for monitoring the impacts of agroforestry practices and precipitation changes in particle size export trends. Frontiers in Earth Science. 2022;10:923447. Available:https://www.frontiersin.org/articles/10.3389/feart.2022.923447/full
11. Kanmegne Tamga D, Latifi H, Ullmann T, Baumhauer R, Thiel M, Bayala J. Modelling the spatial distribution of the classification error of remote sensing data in cocoa agroforestry systems. Agroforestry Systems. 2023;97(1):109-119. Available:https://link.springer.com/article/10.1007/s10457-022-00791-2
12. Hussainzad EA, Yusof MJM. Assessing the economic value of carbon sequestration in Taman Negara Pahang. In IOP Conference Series: Earth and Environmental Science. 2020, July;540(1):012058. IOP Publishing. Available:https://iopscience.iop.org/article/10.1088/1755-1315/540/1/012058/meta
13. Issa S, Dahy B, Ksiksi T, Saleous N. A review of terrestrial carbon assessment methods using geo-spatial technologies with emphasis on arid lands. Remote Sensing. 2020;12(12):2008. Available:https://www.mdpi.com/2072-4292/12/12/2008
14. Lejju J B, John Bosco Nkurunungi. Land use and land cover change influence on soil organic carbon content for a pastoral area: use of geographical information system; 2022. Available:http://www.ir.must.ac.ug/handle/123456789/2444
15. Sharma R, Pradhan L, Kumari M, Bhattacharya P. Assessment of carbon sequestration potential of tree species in

Amity University Campus Noida. Environmental Sciences Proceedings. 2020;3(1):52.
Available:https://www.mdpi.com/2673-4931/3/1/52
16. Bai Y, Cotrufo M F. Grassland soil carbon sequestration: Current understanding, challenges, and solutions. Science. 2022;377(6606):603-608.
Available:https://www.science.org/doi/abs/10.1126/science.abo2380
17. Harari MB, Parola HR, Hartwell CJ, Riegelman A. Literature searches in systematic reviews and meta-analyses: A review, evaluation, and recommendations. Journal of Vocational Behavior. 2020;118:103377.
Available:https://www.sciencedirect.com/science/article/pii/S0001879120300026
18. Rethlefsen ML, Page MJ. PRISMA 2020 and PRISMA-S: common questions on tracking records and the flow diagram. Journal of the Medical Library Association: JMLA. 2022;110(2):253.
19. Lee SW, Koo MJ. PRISMA 2020 statement and guidelines for systematic review and meta-analysis articles, and their underlying mathematics: Life Cycle Committee Recommendations. Life Cycle. 2022;2.
Available:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8876652/
20. Vilar P, Morais TG, Rodrigues NR, Gama I, Monteiro ML, Domingos T, Teixeira RF. Object-based classification approaches for multitemporal identification and monitoring of pastures in agroforestry regions using multispectral unmanned aerial vehicle products. Remote Sensing. 2020;12(5):814.
Available:https://www.mdpi.com/2072-4292/12/5/814
21. Cillis G, Statuto D, Picuno P. Integrating remote-sensed and historical geodata to assess interactions between rural buildings and agroforestry land. Journal of Environmental Engineering and Landscape Management. 2021;29(3):229-243.
Available:https://journals.vilniustech.lt/index.php/JEELM/article/view/15080
22. Lourenço P, Godinho S, Sousa A, Gonçalves A C. Estimating tree aboveground biomass using multispectral satellite-based data in Mediterranean agroforestry system using random forest algorithm. Remote Sensing Applications: Society and Environment. 2021;23:100560.
Available:https://www.sciencedirect.com/science/article/pii/S2352938521000963
23. Zhang T, Zhang W, Yang R, Liu Y Jafari SM. CO 2 capture and storage monitoring based on remote sensing techniques: A review. Journal of Cleaner Production. 2020;281:1-15.
DOI: 10.1016/j.jclepro.2020.124409
24. Liu X, Wang S, Zhuang Q, Jin X, Bian Z, Zhou M, Meng Z, Han C, Guo X, Jin W, et al. A review on carbon source and sink in arable land ecosystems. Land. 2022; 11(4):580.
Available:https://doi.org/10.3390/land11040580
25. Ambaw G, Recha J W, Nigussie A, Solomon D, Radeny M. Soil carbon sequestration potential of climate-smart villages in East African countries. Climate. 2020;8(11):124.
Available:https://www.mdpi.com/2225-1154/8/11/124
26. Keenan PB, Jankowski P. Spatial decision support systems: Three decades on. Decis. Support Syst. 2019;116:64–76.
Available:https://doi.org/10
27. Sun Y, Ma J, Sude B, Lin X, Shang H, Geng B, Quan Z. A UAV-based eddy covariance system for measurement of mass and energy exchange of the ecosystem: preliminary results. Sensors. 2021;21(2):403.
Available:https://www.mdpi.com/1424-8220/21/2/403
28. Burba G. Eddy Covariance Method for Scientific, Regulatory, and Commercial Applications. LI-COR Biosciences; 2022.
Available:https://books.google.com/books?hl=en&lr=&id=acKEEAAAQBAJ&oi=fnd&pg=PA1&dq=Eddy+Covariance+Towers+for+Gas+Exchange+Monitoring&ots=BE7ChIAMYC&sig=DulcwjK2jOFuJbmCwSqUpYnnLrY
29. Berg P, Pace M L, Buelo C D. Air–water gas exchange in lakes and reservoirs measured from a moving platform by underwater eddy covariance. Limnology and Oceanography: Methods. 2020;18(8):424-436.
Available:https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.1002/lom3.10373
30. Ferrara RM, Di Tommasi P, Famulari D. et al. Limitations of an eddy-covariance system in measuring Low ammonia fluxes. Boundary-Layer Meteorol. 2021;180:173–186

Available:https://doi-org.acces.bibl.ulaval.ca/10.1007/s10546-021-00612-6

31. Matthews B, Schume H. Tall tower eddy covariance measurements of CO2 fluxes in Vienna, Austria. Atmospheric Environment. 2022; 274, 118941
Available:https://www.sciencedirect.com/science/article/pii/S1352231022000061
32. Wang Y, Tao F, Chen Y, Yin L. Interactive impacts of climate change and agricultural management on soil organic carbon sequestration potential of cropland in China over the coming decades. Science of The Total Environment. 2022 ;817:153018.
Available:https://www.sciencedirect.com/science/article/pii/S0048969722001073
33. da Silva HM, Júnior JCD, Silveira ML, Junior MAL, Cardoso AS, Vendramini JM. Greenhouse gas mitigation and carbon sequestration potential in humid grassland ecosystems in Brazil: A review. Journal of Environmental Management. 2022;323:116269.
Available:https://www.sciencedirect.com/science/article/pii/S0301479722018424
34. Rodriguez M. Tracking Land Use and Deforestation in the Amazon. 2023.
Available:https://eos.org/articles/tracking-land-use-and-deforestation-in-the-amazon#:~:text=Scientists%20monitoring%20the%20region%20via,protected%20areas%20and%20Indigenous%20lands.
35. Jia J, Wu X. A Multidimensional Assessment Model Using RE–3DSG Sensors on Net ES and GVR for Sustainable and Smart Cities. Sensors. 2020; 20(5), 1259.
Available:https://www.mdpi.com/1424-8220/20/5/1259
36. Seitz D, Fischer L M, Dechow R, Wiesmeier M, Don A. The potential of cover crops to increase soil organic carbon storage in German croplands. Plant and soil. 2023; 488(1-2), 157-173.
Available:https://link.springer.com/article/10.1007/s11104-022-05438-w
37. Shadman S, Khalid P A, Hanafiah M M, Koyande A K, Islam M A, Bhuiyan S A, Show P L. The carbon sequestration potential of urban public parks of densely populated cities to improve environmental sustainability. Sustainable energy technologies and assessments. 2022; 52, 102064.
Available:https://www.sciencedirect.com/science/article/pii/S2213138822001163
38. Duffy C, O'Donoghue C, Ryan M, Styles D, Spillane C. Afforestation: Replacing livestock emissions with carbon sequestration. Journal of environmental management. 2020; 264, 110523.
Available:https://www.sciencedirect.com/science/article/pii/S0301479720304576
39. Ragula A, Chandra KK. Tree species suitable for roadside afforestation and carbon sequestration in Bilaspur, India. Carbon Management. 2020;11(4):369-380.
Available:https://www.tandfonline.com/doi/abs/10.1080/17583004.2020.1790243
40. Burke T, Rowland C, Whyatt J D, Blackburn G A, Abbatt J. Achieving national scale targets for carbon sequestration through afforestation: Geospatial assessment of feasibility and policy implications. Environmental Science & Policy. 2021;124:279-292.
Available:https://www.sciencedirect.com/science/article/pii/S1462901121001830
41. Hou G, Delang CO, Lu X. Afforestation changes soil organic carbon stocks on sloping land: The role of previous land cover and tree type. Ecological Engineering. 2020;152:105860.
Available:https://www.sciencedirect.com/science/article/pii/S0925857420301488
42. Pérez-Silos I, Álvarez-Martínez J M, Barquín J. Large-scale afforestation for ecosystem service provisioning: learning from the past to improve the future. Landscape Ecology. 2021; 36, 3329-3343.
Available:https://link.springer.com/article/10.1007/s10980-021-01306-7
43. Nunes LJ, Meireles CI, Pinto Gomes CJ, Almeida Ribeiro NM. Forest contribution to climate change mitigation: Management oriented to carbon capture and storage. Climate. 2020; 8(2), 21.
Available:https://www.mdpi.com/2225-1154/8/2/21
44. Adetunji A T, Ncube B, Mulidzi R, Lewu F B. Management impact and benefit of cover crops on soil quality: A review. Soil and Tillage Research. 2020; 204, 104717.
Available:https://www.sciencedirect.com/science/article/pii/S0167198720304992.
45. Crystal-Ornela, R, Thapa R, Tully K L. Soil organic carbon is affected by organic amendments, conservation tillage, and cover cropping in organic farming systems:

A meta-analysis. Agriculture, Ecosystems & Environment. 2021; 312, 107356. Available:https://www.sciencedirect.com/science/article/pii/S0167880921000608.

46. Huang Y, Ren W, Grove J, Poffenbarger H, Jacobsen K, Tao B, McNear D. Assessing synergistic effects of no-tillage and cover crops on soil carbon dynamics in a long-term maize cropping system under climate change. Agricultural and Forest Meteorology. 2020; 291, 108090. Available:https://www.sciencedirect.com/science/article/pii/S0168192320301921
47. Pais S, Aquilué N, Campos J, Sil Â, Marcos B, Martínez-Freiría F, Regos A. Mountain farmland protection and fire-smart management jointly reduce fire hazard and enhance biodiversity and carbon sequestration. Ecosystem Services. 2020;44:101143
48. Mishra S, Singh S P. Carbon management framework for sustainable manufacturing using life cycle assessment, IoT and carbon sequestration. Benchmarking: An International Journal. 2021;28(5):1396-1409. Available:https://www.emerald.com/insight/content/doi/10.1108/BIJ-01-2019-0044/full/html
49. Tadesse M, Simane B, Abera W, Tamene L, Ambaw G, Recha J W, Solomon D. The effect of climate-smart agriculture on soil fertility, crop yield, and soil carbon in southern ethiopia. Sustainability. 2021;13(8):4515. Available:https://www.mdpi.com/2071-1050/13/8/4515
50. Bordoloi R, Das B, Tripathi O P, Sahoo U K, Nath A J, Deb S,Tajo L. Satellite-based integrated approaches to modeling spatial carbon stock and carbon sequestration potential of different land uses of Northeast India. Environmental and Sustainability Indicators. 2022;13:100166. Available:https://www.sciencedirect.com/science/article/pii/S2665972721000672

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/119061