Systematic Review

Quantifying Carbon Sequestration in Agroforestry Landscapes: Integrating Remote Sensing and GIS Approaches

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 examines different RS-related techniques utilized in CS assessment, particularly in arid lands, shedding light on the challenges, 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 research 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, RADAR, and 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

Background and Context

Carbon sequestration is capturing, harnessing, and storing carbon dioxide from the atmosphere to reduce its contribution to global warming (Qiu et al., 2020). 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 (Lessmann et al., 2022). Quantifying carbon sequestration is an exciting

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technology that attracts research to ensure sustainable climate change mitigation and land resource management (Arehart et al., 2020). According to Hammad et al. (2020), 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 (Wengert et al., 2021). So, the information is analyzed and interpreted using Geographic Information System (GIS) technology to enable well-informed decision-making (Bindu et al., 2020). Because of their superior ecological study skills, professionals use remote sensors and GIS to evaluate and measure carbon retention in agricultural ecosystems (Xaverius et al., 2020). Plant types, nutritional status, and geographical distribution are all determined using satellite photography (Lizaga et al., 2022).

Carbon sequestration assessments are more accurate and efficient when remote sensing is used with Geographic Information System (GIS) techniques (Kanmegne Tamga et al., 2023). 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 (Hussainzad et al., 2020). 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 (Issa et al., 2020).

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 (Lejju et al., 2022). 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 (Sharma et al., 2020). For climate change resilience and mitigation decisions, this integration improves adaptive environmental management strategies and real-time monitoring.

This study will investigate and report on the link between agroforestry and carbon sequestration by assessing the effectiveness of integrating remote sensing, and GIS approaches to quantify carbon sequestration. 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. Figure 1 shows the process of agroforestry carbon sequestration.

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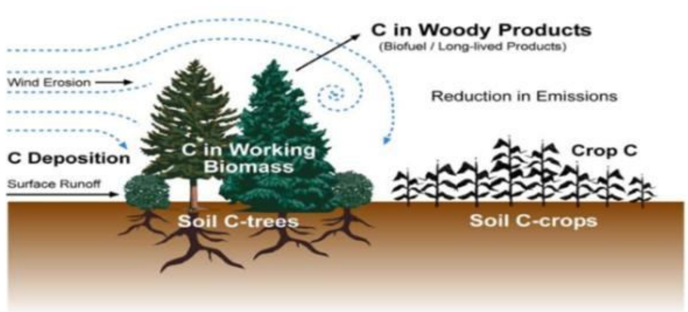

Figure 1:Agroforestry Carbon Sequestration for Climate Change Mitigation

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Statement of the Problem

With the ever-rising global temperatures and adverse weather patterns, Climate change, also known as global warming, 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 for integration of 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. In that light, this study seeks to explore the effectiveness of remote sensing and GIS technologies in quantifying carbon sequestration (Figure 2). 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.

Comment [U10]: Be careful with the terms global warming and climate change. These are two different contexts, please can the author explain more clearly which one will be reviewed in this article?

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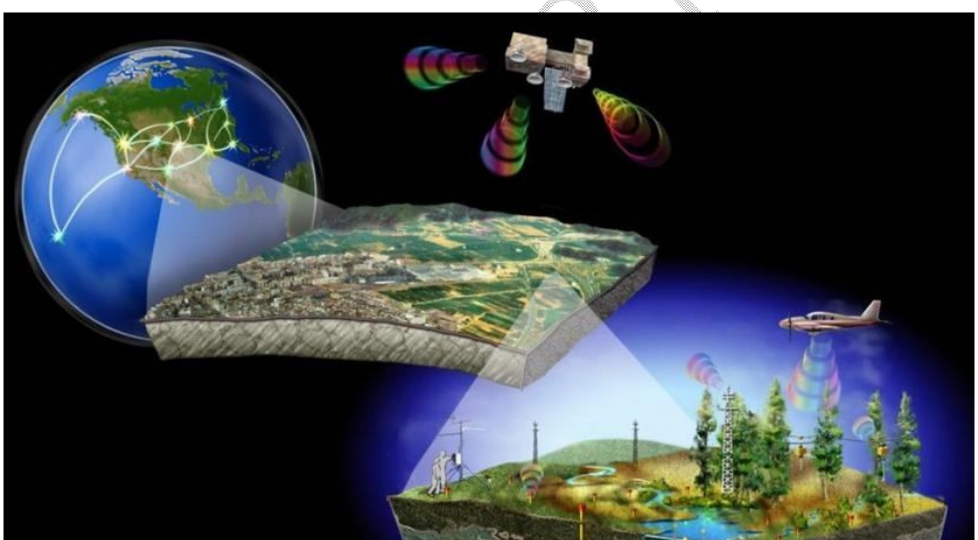

Figure 2:GIS & Remote Sensing

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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 (Bai & Cotrufo, 2022). 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. A GIS approach for remote sensing and photogrammetry is shown in Figure 3.

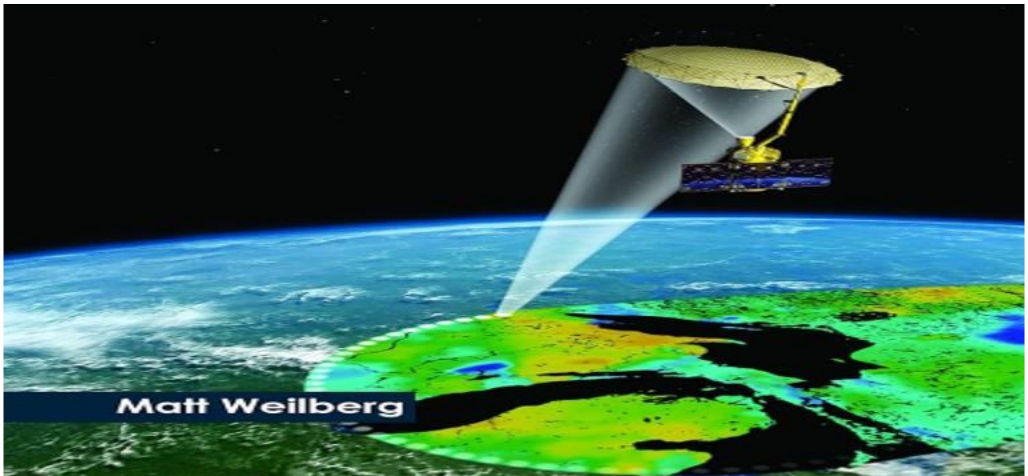

Figure 3: GIS approach for Remote Sensing and Photogrammetry

2. Materials and Methods

To show a strong structure, the study employed systematic literature review approaches (Harari et al., 2020). 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.

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 (Rethlefsen et al., 2021). 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 (Lee et al., 2022). 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.

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3. Results

The efficiency of automated irrigation systems 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 the administration of water in farming.

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3.1 Technologies Used in Quantifying Carbon Sequestration

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3.1.1 Remote Sensing

To assess carbon sequestration, Vilar et al. (2020) 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 (Cillis et al., 2021). Nonetheless, experts may track and gauge carbon stocks in expansive agroforestry systems and forest landscapes thanks to satellite-based remote sensing (Lourenço et al., 2021). LiDAR, or light detection and ranging, is a useful cutting-edge technology that improves measurement precision (Figure 4).

Figure 4: Satellite-Based Remote Sensing Technology

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3.1.2 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. (2020). Hence, Lourenço et al. (2021) 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 (Figure 5).

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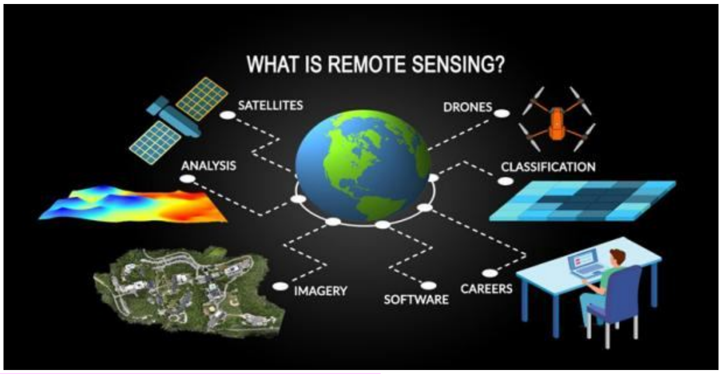

Figure 5: GIS Technology for Carbon Sequestration

3.1.1 Eddy Covariance Towers

Berg et al. (2020) and Sun et al. (2021) 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 (Berg et al., 2020). 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 (Sun et al., 2021).The accuracy in carbon fluxes and seasonal changes helps professionals plan and respond to environmental changes (Burba, 2022). Figure 6 shows the Eddy Covariance Towers for Gas Exchange Monitoring.

Figure 6:Eddy Covariance Towers for Gas Exchange Monitoring

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3.1.4 Carbon Monitoring Systems and Models

Currently, carbon monitoring systems are computational technologies and AI algorithms-driven (Mathews & Schume, 2022). These technologies help simulate and project carbon stocks and variations in various landscapes to mitigate the impact of climate change (Figure 7). Burba (2022) 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 (Sun et al., 2021). 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.

Figure 7:Agrology's Arbiter Carbon Monitoring System

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3.2 Optimizing Carbon Sequestration with Remote Sensing and GIS

Wang et al. (2022) discovered that by leveraging cutting-edge technology, including satellite imaging and aerial data, remote sensing and GIS may maximize carbon sequestration (Bai & Cotrufo, 2022). 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 (Da Silva et al., 2022).

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3.2.1 Decision Support Systems and Precision Scheduling

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Precision scheduling and automated decision-making systems are critical for successful carbon sequestration measures, according to Tan et al. (2022) (Shadman et al., 2022). Ecological managers can obtain real-time information from these tools by integrating data from remote sensing and GIS (Figure 8). Accurate scheduling guarantees precise time frames for cover crop cultivation and reforestation campaigns, enhancing the efficacy of carbon storage programs. Decision-support systems monitor soil characteristics and climate patterns. Tan and colleagues, 2022).

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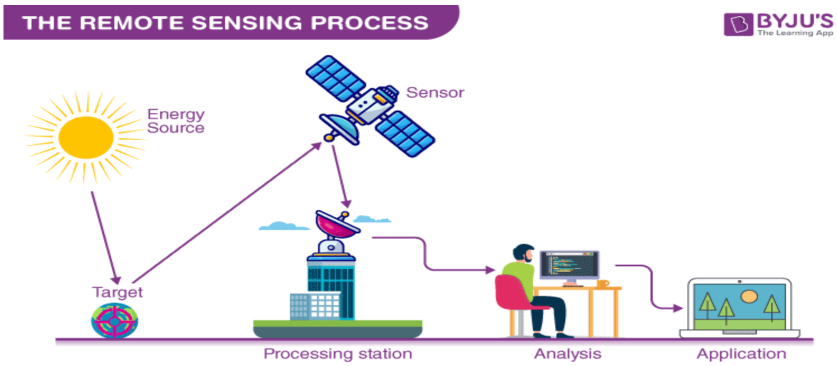

Figure 8: Remote Sensing and GIS Applications

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3.2.2 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 Figure 9). Over time, high-resolution images were gathered using Landsat Sentinel satellite imagery (Rodriguez et al., 2023). 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.

Comment [U31]: In the literature it only says Rodriguez (2023). Even then, it seems like secondary references are not research results

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 (Rodriguez, 2023). 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.

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Figure 9:Tracking Land Use and Deforestation in the Brazilian Amazon

3.3. Challenges Faced in Adopting Remote Sensing and GIS

The difficulties of implementing GIS and remote sensing in carbon sequestration projects are emphasized by Qui et al. (2020). 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.

3.4. Climate Change Impacts and Mitigation Strategies

3.4.1 Climate Change Effects on Carbon Stocks

By upsetting the equilibrium between carbon sources and sinks, climate change severely depletes ecosystems' carbon reserves (Wang et al., 2022). Degradation rates, vegetation development, and the structure of soil carbon are significantly impacted by extreme weather patterns, variations in precipitation, and humidity (Jia & Wu, 2020). 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.

3.4.2 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. (2020). 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 (Wang et al., 2022). These sequestration activities mitigate the adverse effects of climate change by lowering atmospheric carbon concentrations, a critical trigger of global warming (Figure 10).

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Comment [U34]: Qui or Qiu? In the bibliography it is written Qiu. Please pay attention to details like these as they relate to citations and author contributions

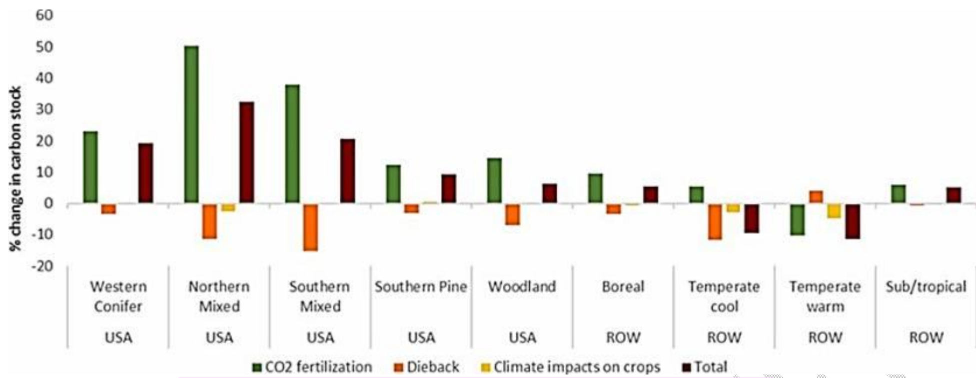

Figure 10: Impact of climate change on aboveground forest carbon stock

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 (Lessmann et al., 2022). 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 (Arehart et al., 2020).

4.1 Overview of Traditional Carbon Sequestration Approaches

Based on the assertions of Seitz et al. (2023), traditional carbon sequestration has been centered around enhancing the role of natural and artificial forests through afforestation and cover cropping activities (Figure 11,12). Afforestation has significantly sequestrated carbon dioxide by capturing and storing carbon dioxide from the atmosphere (Hammad et al., 2020). 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 (Sharma et al., 2020). 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.

Comment [U35]: This image must be the result of research, Please include the appropriate reference as a form of scientific appreciation.

Comment [U36]: Are there measurements using GIS and remote sensing in agricultural vs forest areas for example? If there are any, you can add them to this section

Figure 11: Afforestation

Comment [U37]: What area is this research from? Please include references below the image.

Figure 12: Traditional Carbon Control by Afforestation

Comment [U38]: What area is this research from? Please include references below the image.

Apart from forestry, cover cropping, and no-till farming in Ffigure 13 have been used as traditional ways of soil carbon sequestration because theyhelp maintain ground cover by minimizing soil degradation (Bai & Cotrufo, 2022). By minimizing soil disturbance, cover cropping and no-till farming foster favorable conditions for carbon accumulation (da Silva et al., 2022).

Figure 13: No-till Cover cropping for Carbon Stocking

Comment [U39]: Who did this image come from? Please add the source in the caption below the image

4.1.1 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 (Duffy et al., 2020). 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 (Ragula & Chandra, 2020). 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. (Burke and others, 2021).

Comment [U40]: Is there a situation when an afforestation project has a lot of carbon storage assessed, but when researched using GIS it doesn't? If there is something very interesting discussed in this section

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According to Hou et al. (2020), 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 (Pérez-Silos et al., 2021). Pests, erratic weather patterns, and wildfires are some of the climate change disturbances that reduce its efficiency in sequestering carbon (Nunes et al., 2020).

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 (Adetunji et al., 2020). The viability could need to be improved in regions with limited water supplies, and illnesses and pests could make it less successful. Crystal Ornelas and Associates, 2021 According to Huang et al. (2020), cover crops have a limited ability to sequester carbon because the carbon they store escapes into the atmosphere during decomposition.

Comment [U42]: What does this have to do with the GIS and remote sensing context being discussed?

4.2 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 (Ambaw et al., 2020). Drones, sensors, and satellite photography are used in these techniques to measure and control carbon in agricultural landscapes, supporting efforts to mitigate climate change (Pais et al., 2020). To help farmers maximize fertilization and cover cropping, they also track vegetation growth, soil health, and carbon flux (Mishra & Singh, 2021). Precision agriculture driven by data maximizes the potential for sequestering carbon while improving the efficiency of carbon storage and supporting sustainable farming practices (Tadesse et al., 2021).

A clever method of sequestering energy from biomass, such as plant matter and agricultural leftovers, is carbon capture and storage (BECCS) (Shadman et al., 2022). According to Lizzaga et al. (2022), BECCS is a renewable energy source that aids in removing carbon dioxide from the environment. Programs for afforestation and reforestation can regulate carbon stockings by utilizing GIS mapping and machine learning technology (Wang et al., 2022). Enhancing carbon sequestration for sustainable land use and mitigating climate change can be achieved by combining these technologies with ecological concepts (Jia & Wu, 2020).

Comment [U43]: This sentence has nothing to do with the previous sentence. There should be a connecting sentence that connects BECCS with GIS or remote sensing

4.3 Existing Research on Carbon Sequestration and Climate Change

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 (Kanmegne et al., 2023). 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.

Comment [U44]: I recommend you write down what GIS and remote sensing technology is used, so that it is more focused and clear

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 (Vilar et al., 2020).

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4.4. Gaps and Opportunities in Current Research

4.4.1 Research Gaps

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 (Vilar et al., 2020). Standardizing carbon sequestration approaches across diverse ecosystems is essential to building a knowledge base for reliability and comparability assessments in agroforestry landscapes.

Comment [U45]: This sentence repeats itself as I highlighted above

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 (Lourenco et al., 2021).

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 (Bindu et al., 2020).

4.4.2 Research Opportunities and Future Directions

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) (Issa et al., 2020).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 (Lejju et al., 2022). 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 (Bordoloi et al., 2022). 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.

4.4.3 Future Directions and Recommendations

To increase precision and effectiveness, the study of carbon sequestration in agricultural landscapes must incorporate AI and ML methodologies. 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 (Figure 14).

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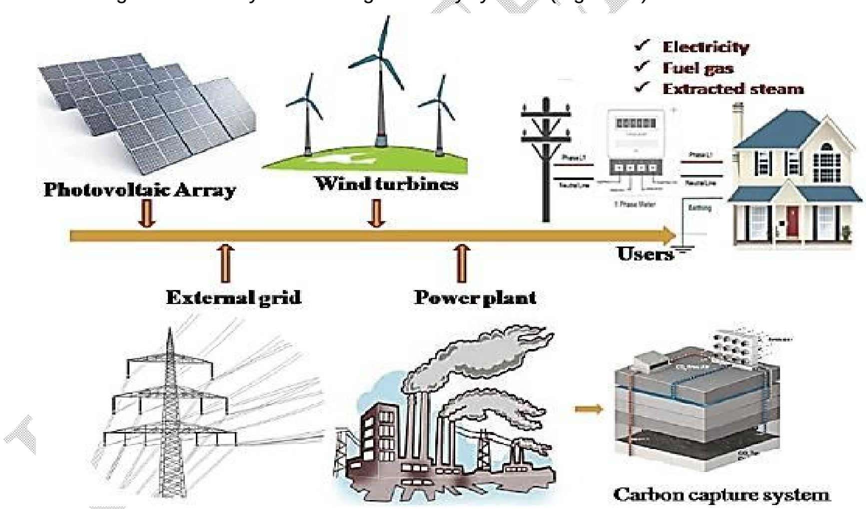

Figure 14: Artificial intelligence-enabled carbon capture

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Dynamic Modelling 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 on the broader impacts of agroforestry systems 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.

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 QIS 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.

Ethical Statement: Not applicable.

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Comment [U48]: What kind of modeling do you mean? If long term, do you mean time series measurements or just based on satellite imagery?

Comment [U49]: In your results and discussion there is still very little information about agroforestry. I suggest just making broader recommendations

Comment [U50]: What does this mean? Currently, almost several countries have geospatial information data. Can this geospatial information be useful for basic ecosystem carbon measurements?

Comment [U51]: I think this sentence does not need to be written. Focus on the results of the technology being reviewed, how useful is it?

Comment [U52]: Has your review compared other ecosystems with agroforestry? Which is good for precision measurements in agroforestry and other ecosystems? This should be included in the conclusion section ... [1]

Comment [U53]: How good is this technology? There should be a percentage advantage of this technology compared to conventional technology

Comment [U54]: What if there are different types of plants on agroforestry lands? Is this level of remote sensing precision accurate for mixed species agroforestry?

Comment [U55]: Pay attention again to the writing of the bibliography and quotations. Numerical system bibliography, while in the body of the text is the author's name. Inconsistent with journal instructions. ... [2]

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Comment [U56]: Please pay attention to writing the author's name in the bibliography

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Comment [U57]: Qiu or Qui??

Comment [U58]: Rodrigues et al??

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