
Remote sensing methods and GIS approaches for carbon Sequestration measurement: A general review

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, 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

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],

34 agricultural landscapes successfully remove considerable greenhouse gases from the surrounding environment by
35 combining croplands and bushes for carbon absorption.

36 Satellite imagery collects information on plants, land coverage, and other surface operations on Earth using drones and
37 aerial photography [5,49,50]. So, the information is analyzed and interpreted using Geographic Information System
38 (GIS) technology to enable well-informed decision-making [6]. Because of their superior ecological study skills, pro-
39 fessionals use remote sensors and GIS to evaluate and measure carbon retention in agricultural ecosystems [7]. Plant
40 types, nutritional status, and geographical distribution are all determined using satellite photography [8].

41 Carbon sequestration assessments are more accurate and efficient when remote sensing is used with Geographic In-
42 formation System (GIS) techniques [9]. Researchers can calculate and visualize the carbon dynamics within agrofore-
43 stry systems thanks to this approach, which also helps quantify biomass and estimate carbon stocks in soil and trees
44 [10]. GIS also considers ecological features such as geography and climate to comprehend factors affecting carbon
45 sequestration rates. Informed decisions about sustainable land use are also made easier by this integration for policy-
46 makers and land managers [11].

47 Monitoring of temporal changes in carbon sequestration, deforestation, vegetation growth, and afforestation activities
48 is made possible by the integration of remote sensing and Geographic Information System (GIS) techniques [12]. By
49 evaluating the long-term viability of agroforestry techniques and offering spatial data for ideal placements and carbon
50 sequestration, GIS is essential to the mitigation of climate change [13]. For climate change resilience and mitigation
51 decisions, this integration improves adaptive environmental management strategies and real-time monitoring.

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

56
57

58 **Statement of the Problem**

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

72

2. Purpose of the Review

73 This study proposes to investigate, evaluate, and report on the role of remote sensing and GIS approaches in quanti-
74 fying carbon sequestration within agroforestry landscape settings. However, using remote sensing and GIS technolo-
75 gy, the project seeks to improve the accuracy and efficiency of carbon sequestration processes in agroforestry land-
76 scapes [14]. This will support land-use planning and sustainable mitigation of climate change. Informed decisions
77 about land use and environmental compliance are facilitated by the study's support for the development of scientific
78 data on the integration of remote sensing and GIS in managing carbon sequestration in agroforestry landscapes. Ma-
79 terials and Methods

80 To show a strong structure, the study employed systematic literature review approaches [15]. Initially, a study topic
81 was chosen, and then relevant materials, including research papers, critiques, short remarks, discussions, and reviews,
82 were retrieved by searching academic databases such as Google Scholar, Scopus Index Journals, Emerald, Elsevier
83 Science Direct, Springer, and Web of Science. From a total of 200 articles, only 40 were selected based on their relevance
84 and significance to the topic of this review.

85 To enhance the caliber and openness of systematic review and meta-analysis reporting, articles are screened using the
86 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which was developed in
87 2009 and revised in 2020 [16]. Hence, it helps raise the bar for reporting standards in a variety of fields by providing
88 authors with an organized framework for communicating and duplicating systematic reviews.

89 Despite its early phases, the research effort did not apply strict criteria for exclusion, enabling a thorough examination
90 free from regional differences [17]. It featured works with a variety of approaches, such as books, student theses, and
91 empirical works like original investigations. Newspaper and magazine articles, which are non-empirical sources, were
92 not included. Undergraduate theses were added to counteract publication bias because peer-reviewed publications
93 typically give preference to research with quantitatively relevant outcomes.

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

99

100

101 3. Results

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

106 3.1 Technologies Used in Quantifying Carbon Sequestration

107 Remote Sensing

108 To assess carbon sequestration, Vilar et al. [18] emphasize the use of remote sensing technologies such as satellite
109 photography and aerial surveys. These technologies offer up-to-date data on variations in land cover, biomass, and
110 vegetation health [19]. Nonetheless, experts may track and gauge carbon stocks in expansive agroforestry systems and
111 forest landscapes thanks to satellite-based remote sensing [20]. LiDAR, or light detection and ranging, is a useful cut-
112 ting-edge technology that improves measurement precision.

113 Satellite photography, aerial surveys, and LiDAR provide crucial land cover, biomass, and vegetation health data for
114 carbon sequestration assessment. These technologies have drawbacks include expensive setup and operating expenses,
115 especially with high-resolution sensors and complex systems like LiDAR. Cloud cover and other atmospheric factors
116 may obscure satellite and aerial images, causing data collecting delays or gaps. Satellites' short return durations may
117 restrict these technologies' temporal resolution for monitoring fast environmental changes[21].

118
119 Remote sensing data is complicated and needs sophisticated processing and analysis, which may be difficult in loca-
120 tions with limited technological resources. Spatial resolution limits may limit the data's value for comprehensive local
121 analysis, and reliance on sunlight for lighting may alter data collection time and consistency. Remote sensing's wide
122 advantages in environmental monitoring frequently exceed its downsides, especially when combined with other data
123 collection methods[22].

124 Geographic Information System (GIS)

125 GIS technology is a crucial tool for quantifying carbon sequestration, as it integrates diverse spatial datasets like cli-
126 mate patterns, topography, and land cover, according to Ambaw et al. [23]. Hence, Lourenço et al. [20] say it helps
127 scientists assess land use effects on carbon dynamics and identify optimal locations for afforestation or reforestation
128 initiatives, enhancing the reliability and accuracy of carbon sequestration efforts.

129 .GIS technology plays a crucial role in measuring carbon sequestration by combining various geographical information
130 and enhancing the precision of evaluating the impact of land use on carbon dynamics. However, it does possess sig-
131 nificant drawbacks. A major constraint is its reliance on the quality and accessibility of input data; flaws in the source
132 data might result in errors in the output, which can impact decision-making procedures. In addition, Geographic In-
133 formation Systems (GIS) need significant computing resources and technical proficiency to efficiently handle and
134 analyze extensive information. The intricate nature of this may provide difficulties in terms of accessibility, especially
135 in settings with low resources, which might impede the general acceptance and efficient use of global carbon man-
136 agement measures[24].

137 Eddy Covariance Towers

138 The Eddy Covariance method, pivotal in atmospheric sciences for measuring gas exchanges between ecosystems and
139 the atmosphere, began taking shape in the early 20th century, rooted in the theoretical work on turbulent diffusion by
140 Sir Geoffrey Ingram Taylor in 1915[25]. It advanced significantly in the mid-20th century with the development of
141 instruments like sonic anemometers, which could accurately measure atmospheric turbulence. The practical applica-
142 tion of these theories and tools led to the widespread use of Eddy Covariance Towers by the late 20th century[26].
143 These towers, equipped with various sensors, have become essential in global networks for studying climate change,

144 carbon cycles, and ecosystem dynamics, continuing to evolve with technological advances in sensors and data analyt-
145 ics. Berg et al.[27] and Sun et al. [25]have highlighted the use of eddy covariance towers, sensor-equipped
146 ground-based equipment, for measuring gas exchanges, including carbon dioxide, and their potential for carbon se-
147 questration [27]. These towers are strategically placed in agriculture fields and woodlands to deliver accurate, real-time
148 carbon fluxes, enabling scientists to compute net carbon content and seasonal ecosystem fluctuations [25].The accuracy
149 in carbon fluxes and seasonal changes helps professionals plan and respond to environmental changes [26].However,
150 Eddy Covariance Towers may face limitations due to their high cost of operation and technological intricacy, necessi-
151 tating ongoing maintenance and calibration to ensure precise measurements. Furthermore, the efficacy of these de-
152 vices relies on consistent meteorological conditions, since significant fluctuations in wind and the absence of turbu-
153 lence may undermine the accuracy of the gathered data[28].

154 **Carbon Monitoring Systems and Models**

155 Currently, carbon monitoring systems are computational technologies and AI algorithms-driven [29]. These technolo-
156 gies help simulate and project carbon stocks and variations in various landscapes to mitigate the impact of climate
157 change . Burba [26] confirms that dynamic global vegetation models (DGVMs) are among the most sophisticated eco-
158 system tools for simulating responses to changing environmental conditions and human activities. Scientists employ
159 DGVMs to explore various environmental scenarios and predict the impact of different variables on carbon sequestra-
160 tion [25]. Experts can create more efficient mitigation measures for climate change by having a better awareness of the
161 other factors that impact carbon capture and storage.

162 **Optimizing Carbon Sequestration with Remote Sensing and GIS**

163 Wang et al. [30] discovered that by leveraging cutting-edge technology, including satellite imaging and aerial data,
164 remote sensing and GIS may maximize carbon sequestration [14]. By precisely identifying the best sites for planting
165 trees or regeneration activities to optimize carbon sequestration possibilities, this improves the efficacy and precision
166 of carbon evaluations [31].

167 **3.2. Case Studies for Successful Implementation of Remote Sensing and GIS**

168 GIS and remote sensing technologies were successfully used by the Brazilian Amazon Rainforest Land Use Changes
169 monitoring project to track and assess land use changes (see Figure 1). Over time, high-resolution images were ga-
170 thered using Landsat Sentinel satellite imagery [32]. Different land use classifications, such as agricultural land, defo-
171 rested areas, and protected reserves, were also classified using GIS tools, satellite data analysis, and land cover classi-
172 fication algorithms.

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

178 Land cover changes were identified by using remote sensing methods to track conservation initiatives and deforesta-
179 tion trends [32]. Analysis of data and representation using GIS techniques revealed areas susceptible to land-use

180 changes and rapid deforestation. The purpose of this material was to promote global cooperation and increase public
181 awareness about the preservation of the Amazon rainforest.



182
183 *Figure1:Tracking Land Use and Deforestation in the Brazilian Amazon[32]*

184 **Challenges Faced in Adopting Remote Sensing and GIS**

185 The difficulties of implementing GIS and remote sensing in carbon sequestration projects are emphasized by Qiu et al.
186 [1]. These difficulties include the expensive starting point, high skill, experience, and training needs, as well as the need
187 to address interoperability and improve data accuracy. Due to the need to balance computing needs with
188 high-resolution data, these problems can be especially difficult for smaller groups or areas with low funding.

189 **3.3. Climate Change Impacts and Mitigation Strategies**

190 **Climate Change Effects on Carbon Stocks**

191 By upsetting the equilibrium between carbon sources and sinks, climate change severely depletes ecosystems' carbon
192 reserves [30]. Degradation rates, vegetation development, and the structure of soil carbon are significantly impacted by
193 extreme weather patterns, variations in precipitation, and humidity [33]. Warmer temperatures, for instance, stimulate
194 the growth of bacteria and quicken the organic matter's breakdown, releasing stored carbon into the sky. The spatial
195 distribution and health of the vegetation are also impacted by these changes, which shape the capability for seques-
196 tering carbon.

197 **Role of Carbon Sequestration in Climate Change Mitigation**

198 Carbon sequestration is the process of taking carbon dioxide out of the atmosphere and storing it in soil and forest
199 reservoirs, according to Xaverius et al. [7]. Forest loss and forestry combined with environmentally friendly land use
200 improve carbon sequestration and the net decrease in carbon dioxide emissions by an equal amount [30]. These se-
201 questration activities mitigate the adverse effects of climate change by lowering atmospheric carbon concentrations, a
202 critical trigger of global warming.

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. [34], traditional carbon sequestration has been centered around enhancing the role of natural and artificial forests through afforestation and cover cropping activities. Afforestation has significantly sequestered 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 [35]. 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 sequestering 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 have been used as traditional ways of soil carbon sequestration because they help maintain ground cover by minimizing soil degradation [14]. By minimizing soil disturbance, cover cropping and no-till farming foster favorable conditions for carbon accumulation [31].

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 [36]. Since these traditional carbon storage approaches could only be used to sequester 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 [37]. 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 [38].

According to Hou et al. [39], 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 [40]. Pests, erratic weather patterns, and wildfires are some of the climate change disturbances that reduce its efficiency in sequestering carbon [41].

240 Growing crop varieties during non-planting seasons to prevent nutrient loss and improve soil is known as "cover
241 cropping," a classic way of storing carbon in the soil. Its reliance on crop types, selection, and climate patterns, however,
242 has constraints [42]. The viability could need to be improved in regions with limited water supplies, and illnesses and
243 pests could make it less successful[43]. According to Huang et al. [44], cover crops have a limited ability to sequester
244 carbon because the carbon they store escapes into the atmosphere during decomposition.

245 **Smart Carbon Sequestration Methods**

246 Precision farming is one example of a smart carbon sequestration strategy that uses cutting-edge technology to max-
247 imize carbon capture and storage [23]. Drones, sensors, and satellite photography are used in these techniques to
248 measure and control carbon in agricultural landscapes, supporting efforts to mitigate climate change [45]. To help
249 farmers maximize fertilization and cover cropping, they also track vegetation growth, soil health, and carbon flux [46].
250 Precision agriculture driven by data maximizes the potential for sequestering carbon while improving the efficiency of
251 carbon storage and supporting sustainable farming practices [47].

252 A clever method of sequestering energy from biomass, such as plant matter and agricultural leftovers, is carbon cap-
253 ture and storage (BECCS) [35]. According to Lizzaga et al. [8], BECCS is a renewable energy source that aids in re-
254 moving carbon dioxide from the environment. This approach complements broader ecological strategies; programs for
255 afforestation and reforestation can regulate carbon stocks by utilizing GIS mapping and machine learning technology
256 [30]. Enhancing carbon sequestration for sustainable land use and mitigating climate change can be achieved by
257 combining these technologies with ecological concepts [33].

258 **Gaps and Opportunities in Current Research**

259 Technology-driven strategies to enhance land use decision-making and mitigate the effects of climate change are the
260 main focus of research on carbon sequestration and climate change. Research emphasizes how trees act as carbon sinks
261 and how to balance the rates of afforestation and deforestation [9]. Additionally, they look at how well various forest
262 types can sequester carbon and how susceptible ecosystems are to climate change, especially in light of shifting pat-
263 terns of temperature and rainfall.

264 To improve carbon sequestration and agrarian efficiency, studies are looking into carbon sequestration in grasslands,
265 wetlands, and agricultural areas. These studies concentrate on sustainable land management techniques including
266 cover crops and agroforestry [18]. Standardizing carbon sequestration approaches across diverse ecosystems is essen-
267 tial to building a knowledge base for reliability and comparability assessments in agroforestry landscapes.

268 A thorough examination of the many agroforestry interacting techniques related to carbon dynamics is lacking in the
269 current studies. Despite some individual studies investigating alley cropping, afforestation, or silvopastoral systems,
270 there still needs to be a gap in reconciling research to assess the combined impact of various agroforestry practices on
271 carbon sequestration [20].

272 Since studies frequently concentrate on localized initiatives, leaving a vacuum in scalability for bigger regions, experts
273 must investigate the capacity for expansion of remote sensing and GIS approaches for carbon sequestration evaluations
274 in agroforestry ecosystems [6].

275 GIS and remote sensing technologies are used in the carbon sequestration project to improve scientific knowledge
276 about sustainable land management techniques. Professionals now have the chance to create and improve cutting-edge
277 technology (UAVs) [11]. To assess carbon sequestration techniques, researchers might establish multidisciplinary
278 partnerships and collaborative efforts that integrate ecological research with economics, social sciences, and policy
279 studies. This will assist in developing economically and environmentally sound practices for farmers and landowners
280 [12]. Longitudinal studies that concentrate on alterations in carbon stock patterns, ecological services, and ecological
281 diversity can be used to investigate the long-term effects of carbon stocking techniques in agroforestry landscapes [48].
282 This will enhance comprehension of the durability and long-term viability of agricultural forests as carbon sinks and
283 assess the efficacy of policies and incentives.

284 **Future Directions and Recommendations**

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

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

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

301 **Development of Decision Support Tools:** Future research must also be directed towards creating user-friendly deci-
302 sion support tools, especially by integrating GIS and remote sensing for policymakers, land managers, and practition-
303 ers. Modern tools are critical for actionable insights and informed decision-making by stakeholders toward optimiz-
304 ing carbon sequestration land-use practices. At the same time, decision-making support tools could incorporate sce-
305 nario analysis, allowing users to explore the potential outcomes of different management strategies under varying
306 climate and land-use scenarios.

307

308 **5. Conclusions**

309 Climate change poses severe challenges to all ecosystems due to changes in world temperature, precipitation patterns,
310 and unpredictable climate events. Major human activities such as cutting down forests, industrialization, and burning
311 fossil fuels contribute to excessive carbon emissions into the atmosphere. Traditional methods such as cover cropping
312 and afforestation have been implemented to reduce carbon stocks and mitigate the effects of climate change. However,
313 serious gaps have yet to be discovered in these approaches. Hence, it calls for technology-driven approaches to ensure
314 precise, accurate, and real-time decision-making. Due to climate change impacts on agroforestry and other ecosystems,

315 remote sensing and GIS technologies enhance carbon sequestration processes by ensuring real-time data collection
316 and decision-making. Professionals must strengthen research in this area to present more efficiency in the effective
317 use of technology to enhance carbon sequestration activities in the agroforestry landscape.
318

319 **Data Availability Statement:** The data used in the present study are available on request from the corresponding
320 author.

321 **Authors contribution:** All the stages of this work have been carried out equally by the authors.

322 **Competing Interests**

323 Authors have declared that they have no known competing financial interests or non-financial interests or personal
324 relationships that could have appeared to influence the work reported in this paper.

325 **Disclaimer (Artificial intelligence)**

326 Option 1:

327 Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT,
328 etc) and text-to-image generators have been used during writing or editing of manuscripts.
329

330 Option 2:

331 Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during
332 writing or editing of manuscripts. This explanation will include list the name, version, model, and source of the ge-
333 nerative AI technology and as well as the all input prompts provided to a generative AI technology
334

335 Details of the AI usage are given below:

336 1.

337 2.

338 3.
339

340 **References**

341 1. Qiu Z, Feng Z, Song Y, Li M, Zhang P. Carbon sequestration potential of forest vegetation in China from 2003 to
342 2050: Predicting Forest vegetation growth based on climate and the environment. Journal of Cleaner Production. 2020;
343 252, 119715. <https://www.sciencedirect.com/science/article/pii/S095965261934585>

-
- 344 2. Lessmann M, Ros G H, Young M D, de Vries W. Global variation in soil carbon sequestration potential through
345 improved cropland management. *Global Change Biology*. 2022; 28(3), 1162-1177.
346 <https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.15954>
- 347 3. Arehart J H, Nelson W S, Srubar III W V. On the theoretical carbon storage and carbon sequestration potential of
348 hempcrete. *Journal of Cleaner Production*. 2020; 266, 121846.
349 <https://www.sciencedirect.com/science/article/pii/S095965262031893X>
- 350 4. Hammad H M, Nauman H M F, Abbas F, Ahmad A, Bakhat H F, Saeed S, Cerdà A. Carbon sequestration po-
351 tential and soil characteristics of various land use systems in arid region. *Journal of environmental management*. 2020;
352 264, 110254. <https://www.sciencedirect.com/science/article/pii/S0301479720301894>
- 353 5. Wengert M, Piepho H P, Astor T, Graß R, Wijesingha J, Wachendorf M. Assessing spatial variability of barley
354 whole crop biomass yield and leaf area index in silvoarable agroforestry systems using UAV-borne remote sensing.
355 *Remote Sensing*. 2021; 13(14), 2751. <https://www.mdpi.com/2072-4292/13/14/2751>
- 356 6. Bindu G, Rajan P, Jishnu E S, Joseph K A. Carbon stock assessment of mangroves using remote sensing and
357 geographic information system. *The Egyptian Journal of Remote Sensing and Space Science*. 2020; 23(1), 1-9.
358 <https://www.sciencedirect.com/science/article/pii/S1110982317303861>
- 359 7. Xaverius F, Loppies S. H D, Siregar K, Vincēviča-Gaile Z, Adinurani P G. Geographic Information system of
360 primary carbon deposit of mangrove forest in Merauke District, Indonesia. In *E3S Web of Conferences*. 2020; (Vol. 190,
361 p. 00011). EDP Sciences.
362 [https://www.e3s-conferences.org/articles/e3sconf/abs/2020/50/e3sconf_icorer2020_00011/e3sconf_icorer2020_00011.ht](https://www.e3s-conferences.org/articles/e3sconf/abs/2020/50/e3sconf_icorer2020_00011/e3sconf_icorer2020_00011.html)
363 [ml](https://www.e3s-conferences.org/articles/e3sconf/abs/2020/50/e3sconf_icorer2020_00011/e3sconf_icorer2020_00011.html)
- 364 8. Lizaga I, Latorre B, Gaspar L, Ramos M C, Navas A. Remote sensing for monitoring the impacts of agroforestry
365 practices and precipitation changes in particle size export trends. *Frontiers in Earth Science*. 2022; 10, 923447.
366 <https://www.frontiersin.org/articles/10.3389/feart.2022.923447/full>
- 367 9. KanmegneTamga D, Latifi H, Ullmann T, Baumhauer R, Thiel M, Bayala J. Modelling the spatial distribution of
368 the classification error of remote sensing data in cocoa agroforestry systems. *Agroforestry Systems*. 2023; 97(1),
369 109-119. <https://link.springer.com/article/10.1007/s10457-022-00791-2>
- 370 10. Hussainzad E A, Yusof M J M. Assessing the economic value of carbon sequestration in Taman Negara Pahang.
371 In *IOP Conference Series: Earth and Environmental Science*. (2020, July); (Vol. 540, No. 1, p. 012058). IOP Publishing.
372 <https://iopscience.iop.org/article/10.1088/1755-1315/540/1/012058/meta>

-
- 373 11. Issa S, Dahy B, Ksiksi T, Saleous N. A review of terrestrial carbon assessment methods using geo-spatial tech-
374 nologies with emphasis on arid lands. *Remote Sensing*. 2020; 12(12), 2008.
375 <https://www.mdpi.com/2072-4292/12/12/2008>
- 376 12. LEJJU J B, JOHN BOSCO N K U R U N U N G I. Land use and land cover change influence on soil organic car-
377 bon content for a pastoral area: use of geographical information system. 2022.
378 <http://www.ir.must.ac.ug/handle/123456789/2444>
- 379 13. Sharma R, Pradhan L, Kumari M, Bhattacharya P. Assessment of carbon sequestration potential of tree species in
380 Amity University Campus Noida. *Environmental Sciences Proceedings*. 2020; 3(1), 52.
381 <https://www.mdpi.com/2673-4931/3/1/52>
- 382 14. Bai Y, Cotrufo M F. Grassland soil carbon sequestration: Current understanding, challenges, and solutions.
383 *Science*. 2022; 377(6606), 603-608. <https://www.science.org/doi/abs/10.1126/science.abo2380>
- 384 15. Harari M B, Parola H R, Hartwell C J, Riegelman A. Literature searches in systematic reviews and meta-analyses:
385 A review, evaluation, and recommendations. *Journal of Vocational Behavior*. 2020; 118, 103377.
386 <https://www.sciencedirect.com/science/article/pii/S0001879120300026>
- 387 16. Rethlefsen M L, Page M J. PRISMA 2020 and PRISMA-S: common questions on tracking records and the flow
388 diagram. *Journal of the Medical Library Association: JMLA*. 2022; 110(2), 253.
- 389 17. Lee S W, Koo M J. PRISMA 2020 statement and guidelines for systematic review and meta-analysis articles, and
390 their underlying mathematics: Life Cycle Committee Recommendations. *Life Cycle*. 2022; 2.
391 <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8876652/>.
- 392 18. Vilar P, Morais T G, Rodrigues N R, Gama I, Monteiro M L, Domingos T, Teixeira R F. Object-based classifica-
393 tion approaches for multitemporal identification and monitoring of pastures in agroforestry regions using multispec-
394 tral unmanned aerial vehicle products. *Remote Sensing*. 2020; 12(5), 814. <https://www.mdpi.com/2072-4292/12/5/814>
- 395 19. Cillis G, Statuto D, Picuno P. Integrating remote-sensed and historical geodata to assess interactions between
396 rural buildings and agroforestry land. *Journal of Environmental Engineering and Landscape Management*. 2021; 29(3),
397 229-243. <https://journals.vilniustech.lt/index.php/JEELM/article/view/15080>
- 398 20. Lourenço P, Godinho S, Sousa A, Gonçalves A C. Estimating tree aboveground biomass using multispectral
399 satellite-based data in Mediterranean agroforestry system using random forest algorithm. *Remote Sensing Applica-*
400 *tions: Society and Environment*. 2021; 23, 100560.
401 <https://www.sciencedirect.com/science/article/pii/S2352938521000963>

-
- 402 21. Zhang T, Zhang W, Yang R, Liu Y, Jafari S M. CO₂ capture and storage monitoring based on remote sensing
403 techniques: A review. *Journal of Cleaner Production*. 2020; 281: 1-15. [10.1016/j.jclepro.2020.124409](https://doi.org/10.1016/j.jclepro.2020.124409)
- 404 22. 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
405 Source and Sink in Arable Land Ecosystems. *Land*. 2022; 11(4):580. <https://doi.org/10.3390/land11040580>
- 406 23. Ambaw G, Recha J W, Nigussie A, Solomon D, Radeny M. Soil carbon sequestration potential of climate-smart
407 villages in East African countries. *Climate*. 2020; 8(11), 124. <https://www.mdpi.com/2225-1154/8/11/124>
- 408 24. Keenan P B, Jankowski P. Spatial Decision Support Systems: Three decades on. *Decis. Support Syst.* 2019; 116,
409 64–76. <https://doi.org/10>
- 410 25. Sun Y, Ma J, Sude B, Lin X, Shang H, Geng B, Quan Z. A UAV-based eddy covariance system for measurement
411 of mass and energy exchange of the ecosystem: preliminary results. *Sensors*. 2021; 21(2), 403.
412 <https://www.mdpi.com/1424-8220/21/2/403>
- 413 26. Burba G. Eddy Covariance Method for Scientific, Regulatory, and Commercial Applications. *LI-COR Biosciences*.
414 2022.
415 <https://books.google.com/books?hl=en&lr=&id=acKEEAAAQBAJ&oi=fnd&pg=PA1&dq=Eddy+Covariance+Towers+fo>
416 [r+Gas+Exchange+Monitoring&ots=BE7ChIAMYC&sig=DulcwjK2jOFwJbmCwSqUpYnnLrY](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=DulcwjK2jOFwJbmCwSqUpYnnLrY)
- 417 27. Berg P, Pace M L, Buelo C D. Air–water gas exchange in lakes and reservoirs measured from a moving platform
418 by underwater eddy covariance. *Limnology and Oceanography: Methods*. 2020; 18(8), 424-436.
419 <https://aslopubs.onlinelibrary.wiley.com/doi/abs/10.1002/lom3.10373>
- 420 28. Ferrara R M, Di Tommasi P, Famulari D. et al. Limitations of an Eddy-Covariance System in Measuring Low
421 Ammonia Fluxes. *Boundary-Layer Meteorol.* 2021; 180, 173–186
422 <https://doi-org.acces.bibl.ulaval.ca/10.1007/s10546-021-00612-6>
- 423 29. Matthews B, Schume H. Tall tower eddy covariance measurements of CO₂ fluxes in Vienna, Austria. *Atmos-*
424 *pheric Environment*. 2022; 274, 118941. <https://www.sciencedirect.com/science/article/pii/S1352231022000061>
- 425 30. Wang Y, Tao F, Chen Y, Yin L. Interactive impacts of climate change and agricultural management on soil or-
426 ganic carbon sequestration potential of cropland in China over the coming decades. *Science of The Total Environment*.
427 2022 ; 817, 153018. <https://www.sciencedirect.com/science/article/pii/S0048969722001073>
- 428 31. da Silva H M, Júnior J C D, Silveira M L, Junior M A L, Cardoso A S, Vendramini J M. Greenhouse gas mitiga-
429 tion and carbon sequestration potential in humid grassland ecosystems in Brazil: A review. *Journal of Environmental*
430 *Management*. 2022; 323, 116269. <https://www.sciencedirect.com/science/article/pii/S0301479722018424>

-
- 431 32. Rodriguez M. Tracking Land Use and Deforestation in the Amazon. 2023.
432 <https://eos.org/articles/tracking-land-use-and-deforestation-in-the-amazon#:~:text=Scientists%20monitoring%20the%20region%20via,protected%20areas%20and%20Indigenous%20lands>.
- 434 33. Jia J, Wu X. A Multidimensional Assessment Model Using RE-3DSG Sensors on Net ES and GVR for Sustainable
435 and Smart Cities. *Sensors*. 2020; 20(5), 1259. <https://www.mdpi.com/1424-8220/20/5/1259>
- 436 34. Seitz D, Fischer L M, Dechow R, Wiesmeier M, Don A. The potential of cover crops to increase soil organic car-
437 bon storage in German croplands. *Plant and soil*. 2023; 488(1-2), 157-173.
438 <https://link.springer.com/article/10.1007/s11104-022-05438-w>
- 439 35. Shadman S, Khalid P A, Hanafiah M M, Koyande A K, Islam M A, Bhuiyan S A, Show P L. The carbon seques-
440 tration potential of urban public parks of densely populated cities to improve environmental sustainability. *Sustaina-
441 ble energy technologies and assessments*. 2022; 52, 102064.
442 <https://www.sciencedirect.com/science/article/pii/S2213138822001163>
- 443 36. Duffy C, O'Donoghue C, Ryan M, Styles D, Spillane C. Afforestation: Replacing livestock emissions with carbon
444 sequestration. *Journal of environmental management*. 2020; 264, 110523.
445 <https://www.sciencedirect.com/science/article/pii/S0301479720304576>
- 446 37. Ragula A, Chandra K K. Tree species suitable for roadside afforestation and carbon sequestration in Bilaspur,
447 India. *Carbon Management*. 2020; 11(4), 369-380. <https://www.tandfonline.com/doi/abs/10.1080/17583004.2020.1790243>
- 448 38. Burke T, Rowland C, Whyatt J D, Blackburn G A, Abbatt J. Achieving national scale targets for carbon seques-
449 tration through afforestation: Geospatial assessment of feasibility and policy implications. *Environmental Science &
450 Policy*. 2021; 124, 279-292. <https://www.sciencedirect.com/science/article/pii/S1462901121001830>
- 451 39. Hou G, Delang C O, Lu X. Afforestation changes soil organic carbon stocks on sloping land: The role of previous
452 land cover and tree type. *Ecological Engineering*. 2020; 152, 105860.
453 <https://www.sciencedirect.com/science/article/pii/S0925857420301488>
- 454 40. Pérez-Silos I, Álvarez-Martínez J M, Barquín J. Large-scale afforestation for ecosystem service provisioning:
455 learning from the past to improve the future. *Landscape Ecology*. 2021; 36, 3329-3343.
456 <https://link.springer.com/article/10.1007/s10980-021-01306-7>
- 457 41. Nunes L J, Meireles C I, Pinto Gomes C J, Almeida Ribeiro N M. Forest contribution to climate change mitiga-
458 tion: Management oriented to carbon capture and storage. *Climate*. 2020; 8(2), 21.
459 <https://www.mdpi.com/2225-1154/8/2/21>.

-
- 460 42. Adetunji A T, Ncube B, Mulidzi R, Lewu F B. Management impact and benefit of cover crops on soil quality: A
461 review. *Soil and Tillage Research*. 2020; 204, 104717.
462 <https://www.sciencedirect.com/science/article/pii/S0167198720304992>.
- 463 43. Crystal-Ornela, R, Thapa R, Tully K L. Soil organic carbon is affected by organic amendments, conservation
464 tillage, and cover cropping in organic farming systems: A meta-analysis. *Agriculture, Ecosystems & Environment*.
465 2021; 312, 107356. <https://www.sciencedirect.com/science/article/pii/S0167880921000608>.
- 466 44. Huang Y, Ren W, Grove J, Poffenbarger H, Jacobsen K, Tao B, McNear D. Assessing synergistic effects of
467 no-tillage and cover crops on soil carbon dynamics in a long-term maize cropping system under climate change.
468 *Agricultural and Forest Meteorology*. 2020; 291, 108090.
469 <https://www.sciencedirect.com/science/article/pii/S0168192320301921>.
- 470 45. Pais S, Aquilué N, Campos J, Sil Á, Marcos B, Martínez-Freiría F, Regos A. Mountain farmland protection and
471 fire-smart management jointly reduce fire hazard and enhance biodiversity and carbon sequestration. *Ecosystem Ser-*
472 *vices*. 2020; 44, 101143
- 473 46. Mishra S, Singh S P. Carbon management framework for sustainable manufacturing using life cycle assessment,
474 IoT and carbon sequestration. *Benchmarking: An International Journal*. 2021; 28(5), 1396-1409.
475 <https://www.emerald.com/insight/content/doi/10.1108/BIJ-01-2019-0044/full/html>
- 476 47. Tadesse M, Simane B, Abera W, Tamene L, Ambaw G, Recha J W, Solomon D. The effect of climate-smart agri-
477 culture on soil fertility, crop yield, and soil carbon in southern ethiopia. *Sustainability*. 2021; 13(8), 4515.
478 <https://www.mdpi.com/2071-1050/13/8/4515>
- 479 48. Bordoloi R, Das B, Tripathi O P, Sahoo U K, Nath A J, Deb S, Tajo L. Satellite-based integrated approaches to
480 modeling spatial carbon stock and carbon sequestration potential of different land uses of Northeast India. *Environ-*
481 *mental and Sustainability Indicators*. 2022; 13, 100166.
482 <https://www.sciencedirect.com/science/article/pii/S2665972721000672>
- 483 49 Rizvi RH, Newaj R, Chaturvedi OP, Prasad R, Handa AK, Alam B. Carbon sequestration and CO₂ absorption by
484 agroforestry systems: An assessment for Central Plateau and Hill region of India. *Journal of Earth System Science*.
485 2019 Apr;128(3):56.
- 486
- 487 50 Banerjee S, Palit D. Application of geospatial technology for agroforestry management. In *Agroforestry for Carbon*
488 *and Ecosystem Management 2024 Jan 1 (pp. 375-383)*. Academic Press.