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Spatio-temporal Dynamics of Land Use/Cover Change and Associated Carbon Stocks in Kanyabaha Wetland in Rukiga District, Uganda

Paul Walakira [a*], Cecilia Gichuki [a], John Muriuki [a], Ezekiel Ndunda [a], Pantaleon M. B. Kasoma [b] and Jackson G. M. Majaliwa [c]

[a] *Department of Environmental Sciences and Education, Kenyatta University, Kenya.*
[b] *Uganda Wildlife Authority, Uganda.*
[c] *Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), Uganda.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Wetlands play an important ecological function of sequestering atmospheric carbon dioxide and thereby moderating adverse impacts of climate change. It is therefore important to understand the dynamics of carbon stocks in wetland vegetation and soils. This study investigated the spatio-temporal dynamics of aboveground, belowground, and total carbon stocks in Kanyabaha Wetland,

**Corresponding author: Email: walakirap@gmail.com;*

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located in Rukiga District, Uganda, spanning from 1990 to 2021. Through field sampling and laboratory analysis, aboveground carbon stocks were assessed by harvesting vegetation biomass and converting it to carbon stock using established conversion factors. Soil samples collected at different depths (0-20cm, 20-50cm, 50-100cm) were analyzed for soil organic carbon content to determine belowground carbon stocks. The study reveals variable spatio-temporal patterns of carbon stocks across land use types, with papyrus-dominated areas exhibiting the highest aboveground carbon stocks (49.66 tC/ha), followed by small-scale farmlands (33.73 tC/ha) and tree plantations (23.01 tC/ha). Conversely, built-up areas exhibit the lowest carbon stocks (1.29 tC/ha). Temporal analysis reveals fluctuating patterns in carbon stocks, with increases observed in built-up areas and small-scale farmlands, and decreases in grasslands and tree plantations that could be due to changes in hydrological cycle. Belowground carbon stocks follow similar trends, with papyrus areas maintaining the highest stocks (39.96 tC/ha), particularly at deeper soil depths that exhibit the highest carbon accumulation due to its extensive network of papyrus rhizome. Changes in land use, especially reclamation of the wetlands for farming and settlements affected carbon capture and storage in the wetland ecosystem. These findings highlight the importance of targeted conservation of natural wetlands and sustainable land management strategies in the Kanyabaha Wetland catchment for enhanced carbon sequestration. Further, in depth studies in the variability of carbon stocks due to various eco-climatic factors and anthropogenic activities are necessary to support sustainable wetland land management practices in Uganda.

Keywords: Carbon stocks; spatial and temporal dynamics; anthropogenic activities.

1. INTRODUCTION

Wetlands are critical ecosystems that provide numerous ecological services, including carbon sequestration, which is essential for mitigating climate change [1,2]. The ability of wetlands to store carbon both above and below ground is influenced by various factors such as vegetation type, soil properties, and land use practices [3,4]. For example, Bridgham [5] conducted a meta-analysis of studies worldwide and found that wetlands sequester large amounts of carbon in soil organic matter, particularly in peatlands and mangrove forests. Additionally, Wetlands provide a myriad of products, services and attributes which have been widely documented [6]. In Uganda for example, wetland products include water, food (plants, fish and wildlife), land (for farming, grazing and forage), craft and building materials, plant mulching material and medicinal plants. Wetland services include flood attenuation, drought control, ground water recharge, erosion and sediment control, wastewater treatment, carbon retention, climate modification, habitat function, eco-tourism, and boat or raft transport. Despite their importance, wetlands are often subjected to significant anthropogenic pressures, leading to land use/cover changes that can alter their carbon storage capacities [7,8].

Kanyabaha Wetland, located in Rukiga District of Uganda, is a vital ecological area that supports diverse land use and cover types, including papyrus, small-scale farmlands, tree plantations, built-up areas, grasslands, and woodlands [9,10]. These different land use types are likely to influence the distribution and amount of carbon stored within the wetland [11,12,13]. However, there is limited comprehensive data on how these land use changes affect carbon stocks over time in this specific region.

Previous studies on carbon stocks in wetlands have predominantly focused on either aboveground or belowground carbon stocks separately, often overlooking the integrated assessment of both components across different land use types and depths [14,15,16]. Additionally, while there is some understanding of the spatial variation in carbon density, the temporal dynamics of carbon stocks in relation to historical land use and land cover changes in Kanyabaha remain underexplored.

2. METHODS

2.1 Study Area

The study was conducted in the Kanyabaha Wetland, located in Rukiga District of Uganda. The wetland covers an area of 33 km^2 and is located between latitude 1.1326°S and longitude 30.0434°E in Kigezi Sub region (Fig. 1). The wetland's soils exhibit a mosaic of textures and compositions, ranging from rich alluvial deposits to mineral-rich substrates. These soils support a varied vegetation profile, shaping the landscape into patches of natural vegetation, interspersed with open water bodies and agricultural fields. The wetland experiences a humid subtropical climate and features a variety of land use and cover types including papyrus, small-scale farmlands, tree plantations, built-up areas, grasslands, and woodlands (Table 1).

2.2 Data Collection

2.2.1 Aboveground carbon stock assessment

To assess the aboveground carbon stock, the different land-use/cover types were determined at a period of time. Satellite images covering the study area for the period (1990, 2001, 2011, and 2021) were downloaded from the USGS Global Visualization geoportal (https://glovis.usgs.gov/), classified using ArcGIS software, and validated in the field both through observations and interview of old people. Field sampling was carried out across the different land use and cover types within the wetland. Sample plots of 1m x 1m were established in representative areas of each land use type. Within these plots, the biomass of vegetation was harvested, dried at 80°C to a constant weight, and then weighed to determine the dry biomass. The dry biomass was subsequently converted to carbon stocks [17].

Table 1. Description of different Land use / Land cover (LULC) categories

LULC category	General Description
Built-up areas	Areas characterized by settlements, roads, and bare ground
Grassland	Vegetation type dominated by large, rolling terrains of grasses, flowers, and herbs
Farmland	Land covered with crops on small plots for household use without advanced and expensive technologies
Papyrus	Tall aquatic sedge plants (*Cyperus papyrus*) with small green-stalked flowers in swampy areas
Woodland	Land covered with densely scattered trees, with or without grassland underneath
Tree Plantation	Large-scale plantations of a single tree species (e.g., Eucalyptus, Coniferous trees) for timber

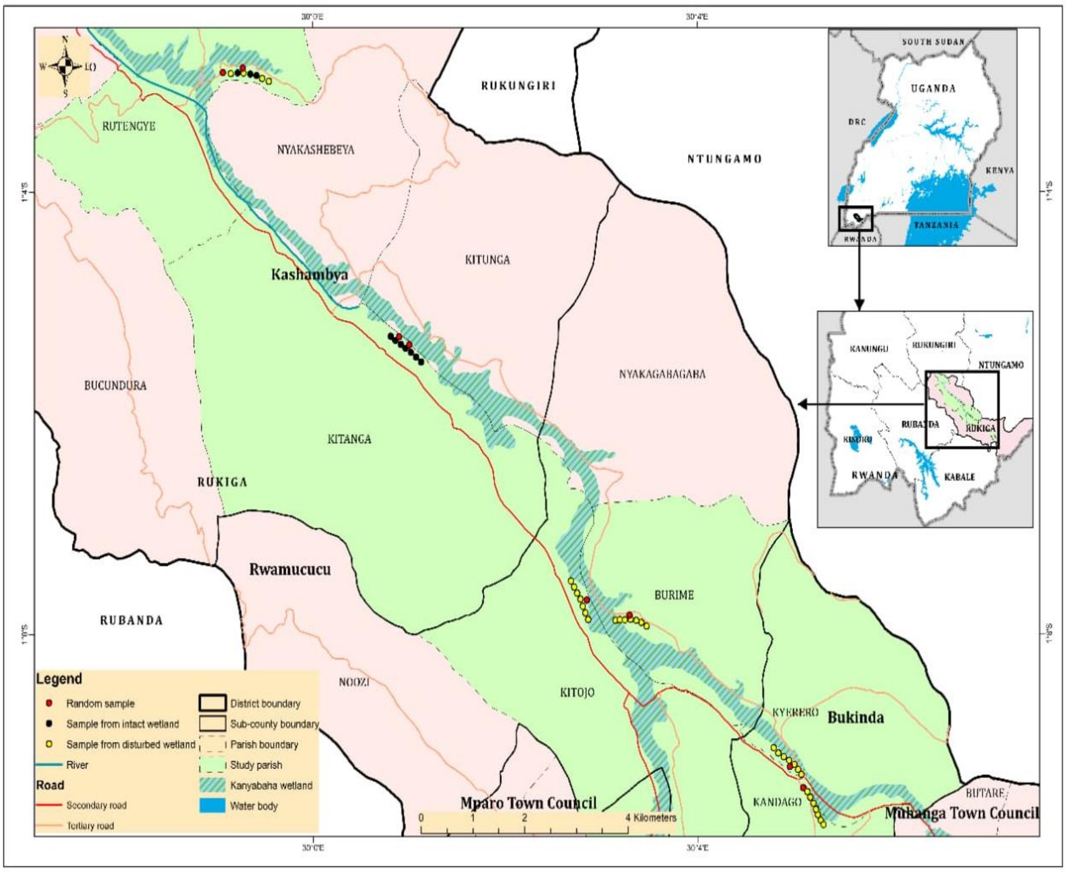

Fig. 1. Map of the Study Area
Source: Developed by the researchers using ArcMap 10.7.1 software

2.2.2 Belowground carbon stock assessment

Soil samples were collected from three depths (0-20 cm, 20-50 cm, and 50-100 cm) within the same plots used for aboveground biomass estimation. These soil samples were dried, sieved, and analyzed for soil organic carbon (SOC) content using the loss on ignition method [18]. Soil bulk density was determined using the core method [18]. Undisturbed soil samples were collected from each depth and the belowground carbon stock was estimated [18].

2.2.3 Total carbon stock assessment

The total carbon stock for each land use and cover type was calculated by summing the aboveground and belowground carbon pools.

2.3 Data Analysis

Regression analysis and descriptive statistics, including mean and standard deviation of carbon stocks, were calculated for each land use and cover type as well as for each soil depth using SPSS version 24. A linear regression was performed to assess the temporal trend in carbon stock across land-use types.

2.4 Quality Control

To ensure consistency and accuracy, standardized protocols were followed for sampling and analysis. Multiple plots were sampled within each land use and cover type to account for variability and improve the reliability of the results. Laboratory equipment was calibrated regularly, and SOC results were validated using known standards.

3. RESULTS

3.1 Aboveground, Belowground, and Total Carbon Stocks in Kanyabaha Wetland

3.1.1 Aboveground carbon stocks

The aboveground carbon stock for the different wetland use/cover types is presented in Fig. 2. Papyrus had the highest aboveground carbon stock with 49.66tC/ha, followed by small-scale farmlands with 33.73tC/ha), and then tree plantations (23.01tC/ha). The least aboveground carbon stock was in built-up areas (1.29 tC/ha) (Fig. 2).

The trend of aboveground carbon stocks for the different wetland use/cover types in Kanyabaha wetland between 1990 and 2021 is presented in Table 2. Between 1990 and 2021, the highest aboveground carbon stocks were observed under papyrus and the least aboveground carbon stocks were observed under built-up areas. Between 1990 and 2021, the aboveground carbon stocks for built-up areas and small-scale farmlands increased whereas that of grasslands and tree plantations decreased. The aboveground carbon stocks for papyrus and woodlands decreased between 1990 and 2011 and then increased between 2011 and 2021 (Table 2).

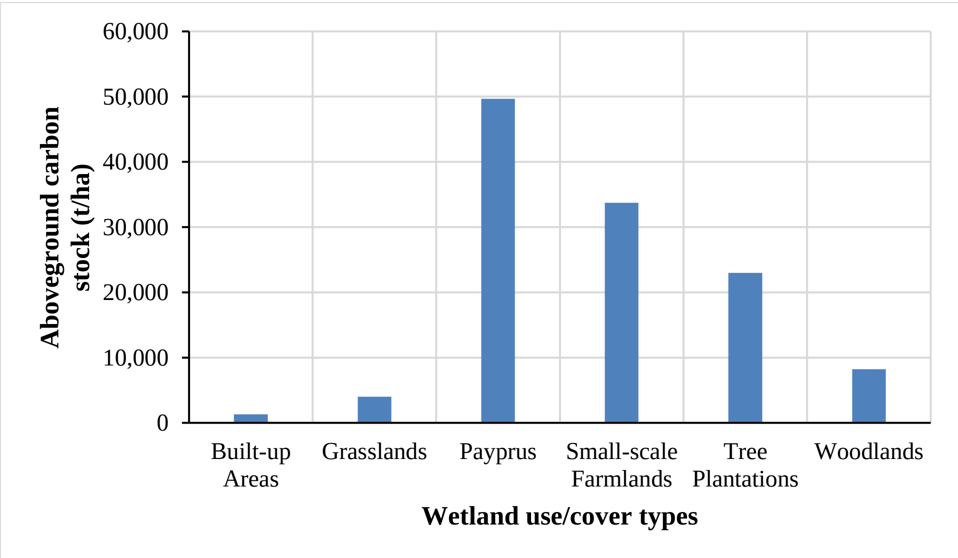

Fig. 2. Aboveground carbon stock for the different wetland use/cover types in Kanyabaha wetland

Table 2. Trend of aboveground carbon stocks in 1990, 2001, 2011, and 2022

Land Use/Cover Type	1990		2001		2011		2021	
	Carbon Stocks (tC/ha)	%	Carbon Stocks (tC/ha)	%	Carbon Stocks (tC/ha)	%	Carbon Stocks (tC/ha)	%
Built-up Areas	0.81	0.80	0.98	1.0	1.13	1.00	1.29	1.10
Grasslands	14.56	14.40	13.57	13.5	5.51	4.90	4.02	3.40
Papyrus	65.47	64.50	58.88	58.6	45.46	40.50	49.67	41.4
Small-scale farmlands	3.18	3.10	9.88	9.8	38.56	34.40	33.73	28.10
Tree Plantations	11.50	11.30	1.03	12.0	17.19	15.30	23.01	19.20
Woodlands	5.92	5.80	5.16	5.1	4.41	3.90	8.21	6.80
Total	101.46	100.00	100.52	100	112.25	100.00	119.91	100.00

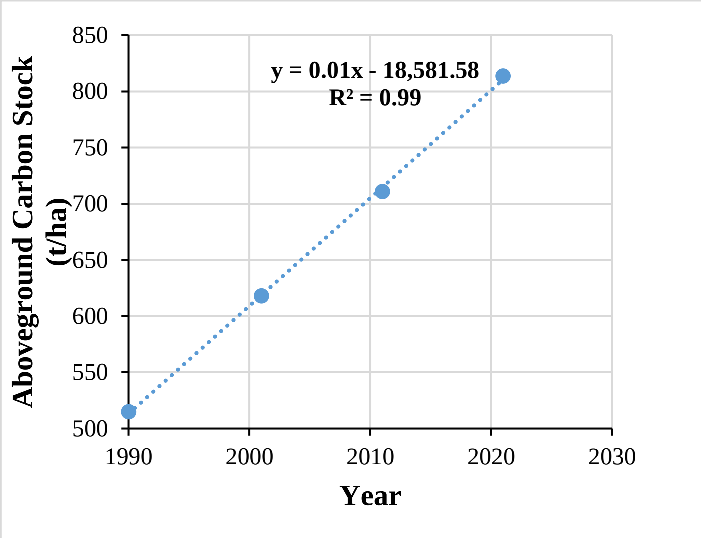

Fig. 3. AGCS for built-up areas between 1990 and 2021

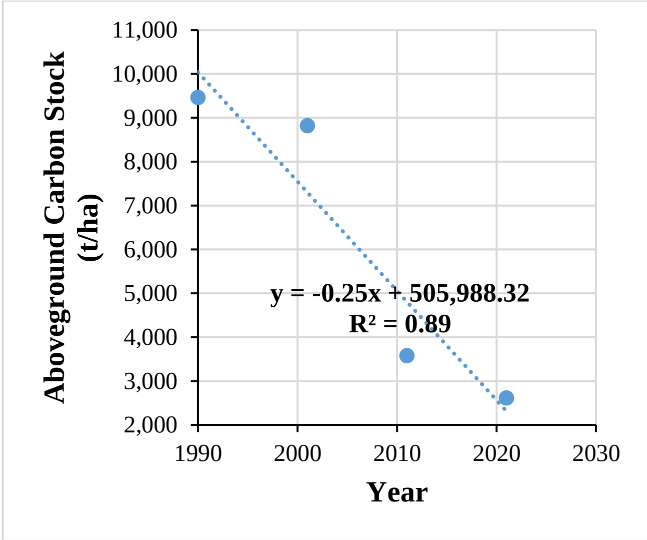

Fig. 4. AGCS for grasslands between 1990 and 2021

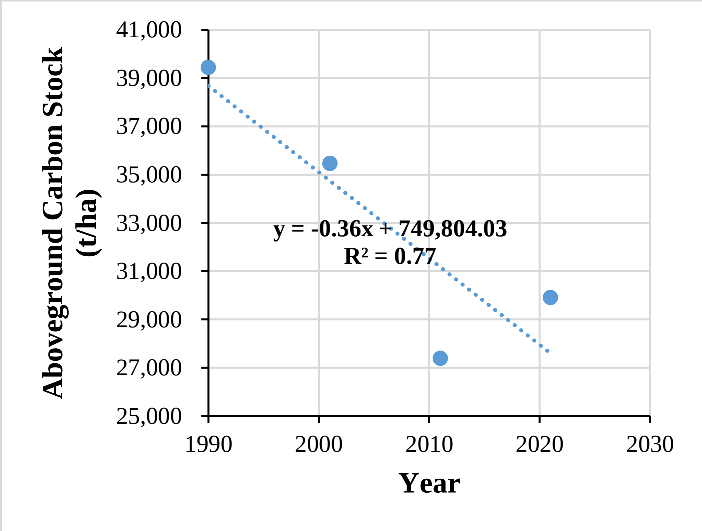

Fig. 5. AGCS for papyrus between 1990 and 2021

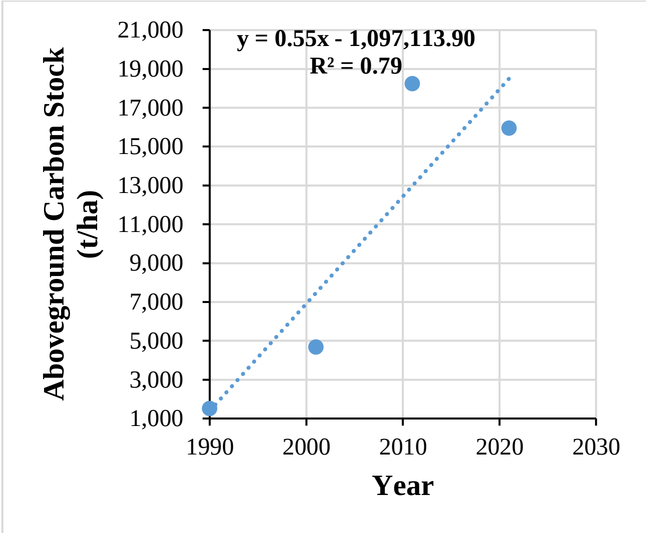

Fig. 6. AGCS for small-scale farmlands between 1990 and 2021

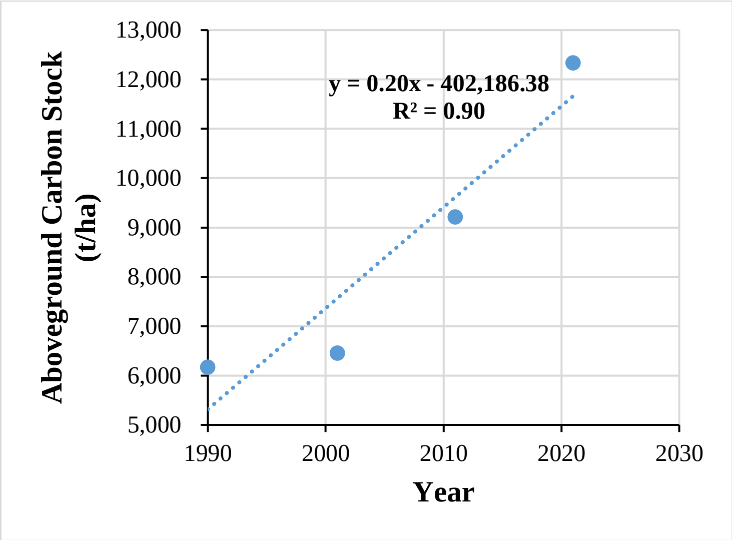

Fig. 7. AGCS for tree plantations between 1990 and 2021

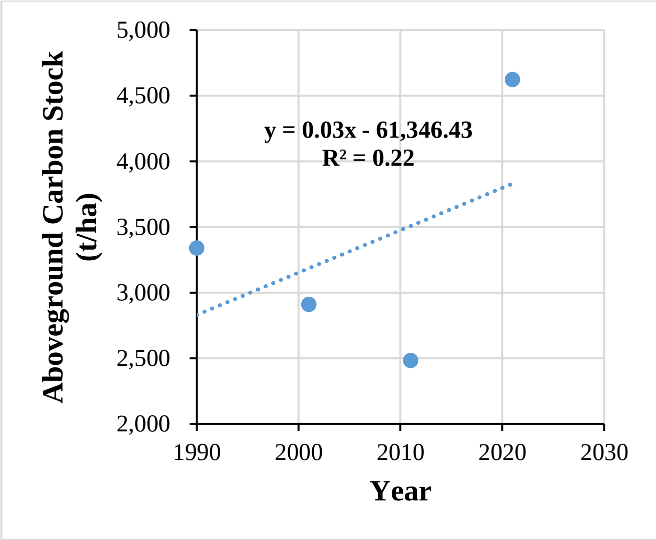

Fig. 8. AGCS for woodlands between 1990 and 2021

Table 3. Trend in belowground carbon stock in Kanyabaha wetland in 1990, 2001, 2011, and 2021 (t/ha)

Year	1990			2001			2011			2021		
Soil depth (cm)	**0-20**	**20-50**	**50-100**	**0-20**	**20-50**	**50-100**	**0-20**	**20-50**	**50-100**	**0-20**	**20-50**	**50-100**
Built-up areas	3.02	425	9.27	3.62	5.10	11.13	4.17	5.86	12.79	4.77	6.71	14.64
Grasslands	17.05	21.19	33.99	15.89	19.74	31.69	6.45	8.01	12.85	4,71	5.85	9.38
Papyrus	27.74	34.02	52.69	24.95	30.60	47.38	19.26	23.62	36.58	21,04	25.80	39.96
Small-scale farmlands	1.53	1.99	307	4.76	6.17	9.55	18.59	24.09	37.23	16.25	21.07	32.58
Tree plantations	5.49	7.50	12.70	5.74	7.84	13.28	8.20	11.20	18.97	10.97	14.99	25.39
Woodlands	7.44	12.21	3153	6.49	10.64	27.49	5.53	9.08	23.44	10.30	16.91	43.65

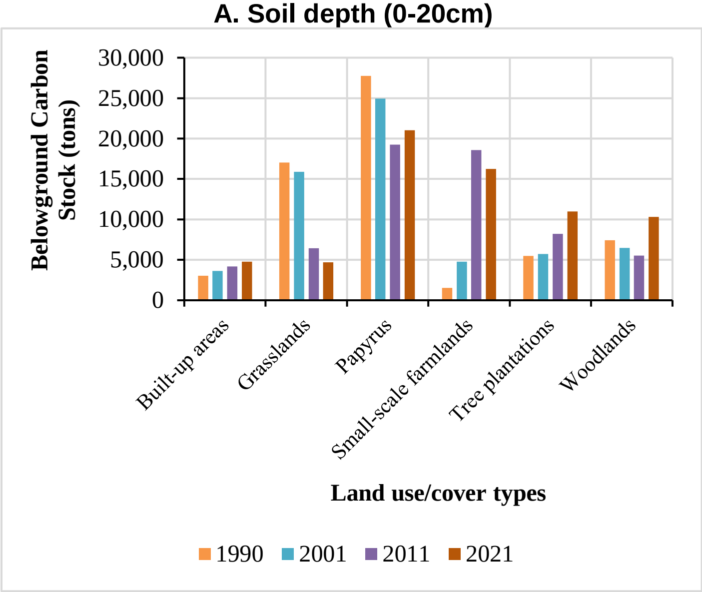

Fig. 9a. Belowground carbon stocks for the different land use/cover types at 0-20cm

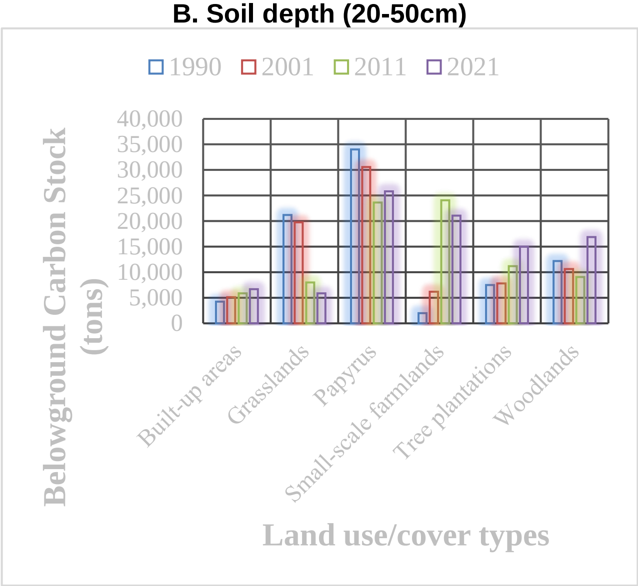

Fig. 9b. Belowground carbon stocks for the different land use/cover types at 20-50cm

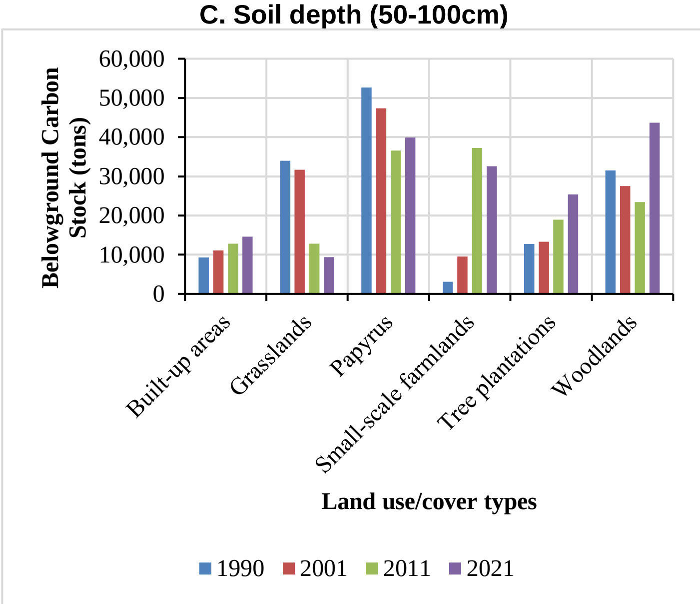

Fig. 9c. Belowground carbon stocks for the different land use/cover types at 50-100cm

There was a strong positive relationship between aboveground carbon stocks (AGCS) for built-up areas (R^2=0.99; P<0.05), grasslands (R^2=0.89; P<0.05), papyrus (R^2=0.77; P<0.05), farmlands (R^2=0.79; P<0.05), and tree plantations (R^2=0.90; P<0.05), and the changes between 1990 and 2021 (Figs. 3-8). The changes in aboveground carbon stocks for woodlands between 1990 and 2021 were weak (R^2=0.22; P<0.05) but positive (Fig. 8). In the period between 1990-2021, AGCS increased in the buildup area, farmland, tree plantations and woodlands, and decreased elsewhere. AGCS under build up area, farmland, tree plantations and woodlands increased lineally at a rate of 0.01tC/year (R^2=0.99; P<0.05), 0.55 tC/year (R^2=0.79; P<0.05), 0.20 tC/year (R^2=0.90; P<0.05) and 0.03 tC/year (R^2=0.22; P<0.05) respectively. While that of grasslands and papyrus decreased gradually at a rate of -0.25 tC/year (R^2=0.89; P<0.05) and -0.36 tC/Year (R^2=0.77; P<0.05) respectively.

3.1.2 Belowground carbon stocks

Table 3 shows the trend of belowground carbon stocks in Kanyabaha wetland in 1990, 2001, 2011, and 2021. In all the years, belowground carbon stocks are relatively high under papyrus. In 1990, the least belowground carbon stock was observed under small-scale farmlands, however, in 2021, grasslands have the least belowground carbon stocks. Between 1990 and 2021, the belowground carbon stocks under tree plantations (R^2=0.91; P<0.05) and built-up areas (R^2=0.99; P<0.05) increased whereas that under grasslands (R^2=0.89; P<0.05) decreased. The belowground carbon stocks under small-scale farmlands (R^2=0.79; P<0.05) increased between 1990 and 2011 and then decreased between 2011 and 2021. For papyrus and woodlands, their belowground carbon stocks decreased between 1990 and 2011 and then increased between 2011 and 2021. For all the years and wetland use/cover types, belowground carbon stocks were highest at the 50-100cm soil layer and least at the 0-20cm soil layer i.e., belowground carbon stocks increased with soil depth.

3.1.3 Belowground carbon stocks for the different land use/cover types across the same soil depth for a period 1990-2021

The belowground carbon stocks were highest under papyrus and lowest under built-up areas as shown below (Fig. 9a, 9a and 9c). The belowground carbon stocks for all the land use/cover types increased with soil depth. The belowground carbon stocks for built-up areas and tree plantations increased between 1990 and 2021. The belowground carbon stocks for grasslands decreased between 1990 and 2021. The belowground carbon stocks for papyrus and woodlands decreased between 1990 and 2011 and then increased between 2011 and 2021. The belowground carbon stocks for small-scale farmlands increased between 1990 and 2011, and then decreased between 2011 and 2021.

3.1.4 Total carbon stocks

The assessment of total carbon stock in Kanyabaha wetland is presented in (Fig. 10) below. Between 1990 and 2021, total carbon stock is relatively higher in the papyrus class. Small-scale farmlands had the least total carbon stock in 1990 whereas in 2021, grasslands had the least total carbon stock. Between 1990 and 2021, the total carbon stocks under tree plantations (R^2=0.91; P<0.05) and built-up areas (R^2=0.99; P<0.05) increased whereas that under grasslands (R^2=0.98; P<0.05) decreased. The total carbon stocks under small-scale farmlands (R^2=0.79; P<0.05) increased between 1990 and 2011 and then decreased between 2011 and 2021. The total carbon stocks for papyrus (R^2=0.76; P<0.05) and woodlands (R^2=0.23; P<0.05) decreased between 1990 and 2011 and then increased between 2011 and 2021 (Fig. 10).

3.2 Discussion

The findings of this study highlight the significant variability in carbon stocks across different land use and cover types within Kanyabaha Wetland, Rukiga District, Uganda. The assessment reveals distinct patterns in aboveground, belowground, and total carbon stocks, influenced by both spatial distribution and temporal changes from 1990 to 2021.

3.2.1 Aboveground carbon stocks

The aboveground carbon stock data indicates that papyrus-dominated areas hold the highest aboveground carbon stocks at 49.66 tC/ha, significantly outstripping other land use types. This can be attributed to the dense biomass and rapid growth rate of papyrus plants, which are well-adapted to wetland conditions. Small-scale farmlands and tree plantations also exhibit substantial aboveground carbon stocks,

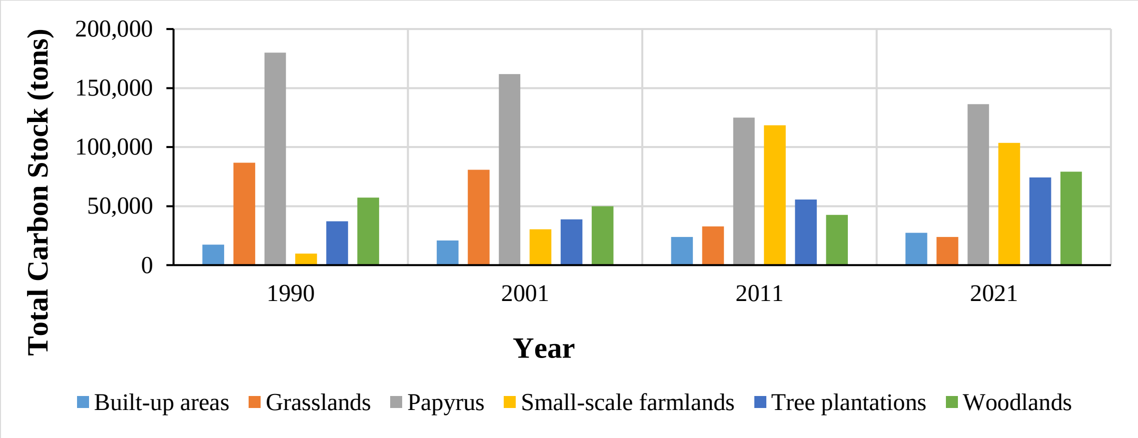

Fig. 10. Trend of total carbon stocks in Kanyabaha wetland in 1990, 2001, 2011, 2021

with 33.73 tC/ha and 23.01 tC/ha, respectively. The relatively high carbon stocks in small-scale farmlands may result from the incorporation of agroforestry practices that integrate trees with crops [19]. Conversely, built-up areas show the lowest aboveground carbon stock (1.29 tC/ha), reflecting the minimal vegetation cover typical of developed regions [19].

3.2.2 Temporal trends in aboveground carbon stocks

The temporal analysis from 1990 to 2021 demonstrates notable shifts in aboveground carbon stocks across different land use types. Papyrus consistently holds the highest stocks, although there was a decline from 1990 to 2011, followed by a recovery between 2011 and 2021. This fluctuation could be linked to changes in hydrological conditions or anthropogenic activities such as harvesting and land conversion.

Small-scale farmlands show a significant increase in aboveground carbon stocks over the study period, possibly due to the expansion of agricultural activities and improved land management practices [20]. In contrast, grasslands and tree plantations experienced a decline in aboveground carbon stocks, which might be due to deforestation, degradation, or conversion to other land uses [21].

3.2.3 Belowground carbon stocks

The belowground carbon stock assessment reveals that, similar to aboveground stocks, papyrus areas contain the highest belowground carbon stocks across all years, with a notable concentration at the 50-100 cm soil depth. This trend highlights the deep root systems of papyrus, which effectively sequester carbon in deeper soil layers [2,22]. The high belowground carbon stocks associated with papyrus can be attributed to its extensive rhizomes that can accumulate significant amounts of organic matter over time, contributing to carbon storage in wetland soils [23]. Secondly, the slow decomposition of papyrus plants allows organic carbon to persist in the soil for extended periods rather than being quickly released back into the atmosphere as carbon dioxide [2]. Thirdly, papyrus contributes to maintaining the wetland carbon stocks through its growth and decomposition processes, influencing the overall carbon balance of wetland ecosystems [24]. This finding confers with Hedman [25] who found papyrus to have the highest belowground carbon stock in Masaka district, Uganda (331.1 ± 437.8 t C ha^{-1}).

Built-up areas exhibited the lowest belowground carbon stocks in Rushebeya wetland. Odeke [24] also observed the areas disturbed with built-up in Lubigi wetland, Kampala, Uganda to have the least soil organic carbon. Conversion of wetland areas to built-up areas such as settlements and roads often involves clearing natural vegetation and altering the soil structure. Trees, shrubs, and other vegetation that store carbon in their biomass and roots are removed or significantly reduced, contributing to the decreased organic matter input into the soil [26]. In addition, construction activities lead to soil compaction. Compacted soils have reduced pore spaces and air circulation, limiting the ability of soil organisms to decompose organic matter and store carbon [27]. However, over time, belowground carbon stocks in built-up areas and tree plantations have increased, reflecting ongoing urbanization and reforestation efforts [28,29].

The increase in belowground carbon stocks with soil depth can be explained by various factors and processes. Firstly, organic matter can accumulate over time in the deep soil profile due to slower decomposition rates and reduced disturbance compared to surface layers [30]. Secondly, deeper soil layers often have higher clay content or aggregates that physically protect organic matter from decomposition [31]. This protection can shield organic carbon from microbial degradation, allowing it to persist and accumulate over time. Lastly, decomposition rates generally decrease with increasing soil depth due to factors like reduced oxygen availability, lower temperatures, and fewer microbial activities [32]. Slower decomposition rates mean that organic matter persists longer in deeper soil layers, contributing to higher carbon stocks. This finding was also reported by Twongyirwe [33] in their study about the variability of soil organic carbon in the afro-montane landscape of South-Western Uganda.

The increase of belowground carbon stocks with time under tree plantations can be attributed to the accumulation of root biomass. Over time, trees accumulate more biomass in their roots and belowground structures such as root collars, and root crowns [34]. This biomass includes structural roots, fine roots, and root hairs, all of which contribute to belowground carbon stocks. Secondly, trees allocate a significant proportion of the carbon they fix through photosynthesis to belowground parts, especially as they mature [35]. This allocation supports root growth, maintenance, and the storage of reserves needed for growth and response to environmental stresses. Lastly, the turnover of roots and the decomposition of older root material contribute to the accumulation of carbon in the soil over time [36]. This finding deviates from those of Zhang [37] who observed the belowground carbon stocks in Uganda's forest land to decrease by 63.2% between 2006 and 2010. The decline in belowground carbon stocks was attributed to the changes in land use and land cover types.

The belowground carbon stocks for grasslands in Rushebeya wetland decreased between 1990 and 2021, which could be attributed to soil degradation and reduced vegetation cover [38,39,40,41]. Makuma-Massa [42] recorded a similar finding in Kabarole district of Western Uganda. The decrease in belowground carbon stocks with time in wetland grassland systems can be attributed to continuous grazing, that compacts soils, reducing root growth and biomass production [43]. This reduction in root biomass decreases the carbon stored belowground over time. In addition, grasslands are often subject to natural disturbances such as fires, as well as human-induced disturbances like agricultural practices or land conversion [44]. These disturbances can disrupt root systems, reduce vegetation cover, and accelerate the decomposition of organic matter, thereby reducing belowground carbon stocks.

The decrease in belowground carbon stocks for papyrus and woodlands between 1990 and 2011 can be explained by conversion to agriculture and overharvesting of papyrus for handicrafts. As wetland areas shrink or become isolated, the overall biomass of papyrus and woodland plants and their belowground carbon stocks decline [45]. Similarly, overharvesting can reduce the biomass of papyrus and woodland plants, including their belowground parts such as roots and rhizomes, leading to decreased belowground carbon stocks [46]. Extreme weather events, such as droughts or floods, can stress papyrus and woodland plants and reduce their biomass, including belowground carbon stocks [25]. The increase in belowground carbon stocks for papyrus and woodlands between 2011 and 2021 can be attributed to restoration efforts of the district local government as well as the Ministry of Water and Environment, Uganda.

The belowground carbon stocks for small-scale farmlands in Rushebeya wetland increased between 1990 and 2011. This finding confers with Zhang [37] who observed the belowground carbon stocks in the cultivated lands of Uganda to have increased by 35.7% between 2006 and 2010. The increase of belowground carbon stocks in small-scale farmlands can be attributed to the application of cover crops that contribute organic matter to the soil through root biomass [47]. Secondly, reduced tillage practices by farmers minimize soil disturbance, which helps preserve soil organic carbon and promotes its accumulation over time [48]. Thirdly, application of organic amendments such as compost, manure, or crop residues can increase soil organic carbon levels [49]. These amendments provide a source of organic matter that decomposes slowly, contributing to belowground carbon stocks. Lastly, integrating trees into agricultural landscapes through agroforestry systems or tree planting initiatives can enhance belowground carbon stocks [50]. Trees contribute to soil carbon through litterfall, root biomass, and the formation of stable organic matter in the soil. The increase in the acreage of small-scale farmlands in the wetland coupled with the above-mentioned farm management interventions lead to an increase in belowground carbon stocks in farmlands with time. The decrease in belowground carbon stocks for small-scale farmlands between 2011 and 2021 can be attributed to restoration efforts of the district local government as well as the Ministry of Water and Environment, Uganda. Wetland restoration interventions are associated with cutting and/or slashing of crops in wetlands and this leads to an overall reduction in their belowground carbon stocks.

3.2.4 Total carbon stocks

When combining aboveground and belowground data, the total carbon stock trends highlight that papyrus areas maintain the highest total carbon stocks, emphasizing the critical role of papyrus in carbon sequestration within the wetland. Between 1990 and 2021, total carbon stocks in tree plantations and built-up areas have increased, while those in grasslands have decreased, mirroring the patterns observed in both aboveground and belowground carbon stocks. The observed increase in total carbon stocks under built-up areas may seem counterintuitive but could be due to the establishment of green spaces and urban forestry initiatives that enhance carbon storage despite urban expansion [51].

3.2.5 Implications for wetland management

These findings show the importance of land use and cover type in determining carbon sequestration potential in wetlands. The high carbon storage capacity of papyrus suggests that conservation and restoration of papyrus-dominated areas could be a vital strategy for enhancing carbon sequestration in Kanyabaha Wetland. Additionally, promoting sustainable agricultural practices in small-scale farmlands and reforestation in degraded areas could further boost carbon stocks. Understanding these dynamics is crucial for informing wetland management policies and practices aimed at maximizing carbon sequestration, mitigating climate change, and preserving the ecological integrity of Kanyabaha Wetland. Future research should focus on the impacts of specific land management practices on carbon dynamics and explore the potential for integrating carbon sequestration goals with other ecosystem services provided by wetlands.

4. CONCLUSION

The study reveals significant insights into the carbon sequestration potential and variability across different land use and cover types. The findings indicate that papyrus-dominated areas are the most effective in sequestering carbon, both above and below ground, highlighting their critical role in the wetland's carbon dynamics. Small-scale farmlands and tree plantations also contribute significantly to carbon stocks, reflecting the positive impact of agroforestry and reforestation practices.

Conversely, built-up areas exhibit the lowest carbon stocks, underscoring the detrimental impact of urbanization on carbon storage. The temporal trends from 1990 to 2021 show fluctuating patterns in carbon stocks, with increases in built-up areas and small-scale farmlands, and decreases in grasslands and tree plantations. These trends reflect the ongoing changes in land use and management practices within the wetland.

The data on belowground carbon stocks further emphasizes the importance of soil depth in carbon sequestration, with deeper soil layers in papyrus areas showing higher carbon concentrations. The increase in belowground carbon stocks in tree plantations and built-up areas over time suggests potential benefits from reforestation and urban green initiatives.

Overall, this study highlights the necessity of targeted conservation and sustainable management strategies to enhance carbon sequestration in Kanyabaha Wetland. Preserving and restoring papyrus-dominated areas, promoting sustainable agricultural practices, and supporting reforestation efforts are vital actions to maximize the wetland's carbon storage capacity. These findings provide a valuable foundation for informing wetland management policies and contribute to broader efforts in climate change mitigation and ecological preservation. Future research should continue to explore the interactions between land use practices and carbon dynamics to optimize wetland management for enhanced carbon sequestration and ecosystem health.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

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

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pant HK. Wetland preservations: Solutions to tackling greenhouse gas emissions. In Handbook of Nature-based Solutions to Mitigation and Adaptation to Climate Change. Cham: Springer International Publishing. 2023;1-15.
2. Lolu AJ, Ahluwalia AS, Sidhu MC, Reshi ZA, Mandotra SK. Carbon sequestration and storage by wetlands: Implications in the climate change scenario. Restoration of Wetland Ecosystem: A Trajectory towards a Sustainable Environment. 2020;45-58.
3. Tan L, Ge Z, Ji Y, Lai DY, Temmerman S, Li S, Tang J. Land use and land cover changes in coastal and inland wetlands cause soil carbon and nitrogen loss. Global Ecology and Biogeography. 2022;31(12): 2541-2563.
4. Chen B, Zhang M, Yang R, Tang W. Spatiotemporal variations in the carbon sequestration capacity of Plateau Lake Wetlands Regulated by Land Use Control under Policy Guidance. Land. 2023;12(9): 1695.
5. Bridgham SD, Megonigal JP, Keller JK, Bliss NB, Trettin C. The carbon balance of North American wetlands. Wetlands. 2006;26(4):889-916.
6. Rebelo LM, McCartney MP, Finlayson CM. Wetlands of Sub-Saharan Africa: Distribution and contribution of agriculture to livelihoods. Wetlands Ecology and Management. 2010;18:557-572.
7. Karmakar S, Islam SS, Sen K, Ghosh S, Midya S. Climate crisis and wetland ecosystem sustainability. In Climate Crisis: Adaptive Approaches and Sustainability. Cham: Springer Nature Switzerland. 2024;529-549.
8. Navarro N, Rodríguez-Santalla I. Coastal wetlands. Journal of Marine Science and Engineering. 2023;1(4):767.
9. Tweheyo M, Amanya B, Turyahabwe N. Feeding patterns of sitatunga (Tragelaphus Speki) in the Rushebeya-Kanyabaha wetland, South Western Uganda; 2010. Retrieved May 24, 2024.
   Available:https://www.researchgate.net/publication/230274731_Feeding_patterns_of_sitatunga_Tragelaphus_Speki_in_the_Rushebeya-Kanyabaha_wetland_South_Western_Uganda
10. Tugume G. Environmentalists Warn Rukiga Residents Off Rushebeya-Kanyabaha Wetland. Chimpreports; 2022, June 29.
    Available:https://chimpreports.com/environmentalists-warn-rukiga-residents-off-rushebeya-kanyabaha-wetland/
11. Kadoma A. Understanding stakeholder perceptions of wetland ecosystem services to support conservation and restoration activities in Wakiso District, Uganda (Doctoral dissertation, University of Glasgow); 2023.
12. Kusiima SK, Egeru A, Namaalwa J, Byakagaba P, Mfitumukiza D, Mukwaya P, et al. Interconnectedness of ecosystem services potential with land use/land cover change Dynamics in Western Uganda. Land. 2022;11(11):2056.
13. Mavindu M, Ogello OE, Outa ON, Ouko OK, Obiero OK, Mboya BJ, Mukaburu OB. Threats to aquatic biodiversity and possible management strategies in Lake Victoria; 2024.
14. Dayathilake DDTL, Lokupitiya E, Wijeratne VPIS. Estimation of aboveground and belowground carbon stocks in urban freshwater wetlands of Sri Lanka. Carbon Balance and Management. 2020;15:1-10.
15. Tangen BA, Bansal S. Soil organic carbon stocks and sequestration rates of inland, freshwater wetlands: Sources of variability and uncertainty. Science of the Total Environment. 2020;749:141444.
16. Meng Y, Bai J, Gou R, Cui X, Feng J, Dai Z, et al. Relationships between above-and below-ground carbon stocks in mangrove forests facilitate better estimation of total mangrove blue carbon. Carbon Balance and Management. 2021;16:1-14.
17. Hairiah K, Sitompul SM, Van Noordwijk M, Palm C. Methods for sampling carbon stocks above and below ground. Bogor, Indonesia: ICRAF. 2001;1-23.
18. Agus F, Hairiah K, Mulyani A. Measuring carbon stock in peat soils: practical guidelines World agroforestry Centre-ICRAF Southeast Asia and Indonesian Centre for Agricultural Land Resources Research and Development. Land Resour. Res. and Dev, Bogor, Indonesia; 2011.
19. Mardiatmoko G. Biomass-based agroforestry for sustainable land use

planning and management. In Agroforestry for Carbon and Ecosystem Management. Academic Press. 2024;283-293.
20. Kumar R, Singh A, Datta A, Yadav RP, Dinesh D, Verma K. Carbon sequestration in degraded lands: Current prospects, practices, and future strategies. In Plans and Policies for Soil Organic Carbon Management in Agriculture. Singapore: Springer Nature Singapore. 2022;221-255.
21. Shoukat A, Khan SM, Ali S, Ahmad Z. Carbon flux and budget of agroforestry. In Agroforestry for Carbon and Ecosystem Management. Academic Press. 2024;123-134.
22. Yin X, Jiang C, Xu S, Yu X, Yin X, Wang J, et al. Greenhouse gases emissions of constructed wetlands: Mechanisms and affecting factors. Water. 2023;15(16):2871
23. Saunders MJ, Kansiime F, Jones MB. Reviewing the carbon cycle dynamics and carbon sequestration potential of Cyperus papyrus L. wetlands in tropical Africa. Wetlands Ecology and Management. 2014;22(2):143–155. Available:https://doi.org/10.1007/s11273-013-9314-6
24. Odeke C. Wetland degradation and carbon sequestration potential: A case of Lubigi wetland, Uganda. In Kyambogo University; 2019.
25. Hedman A. Effects of land use on wetland carbon storage and ecosystem services in the tropics A first estimation investing rural wetlands in central and eastern Uganda. In Umea Universitet; 2019.
26. Zhang,C, Tian H, Pan S, Lockaby G, Chappelka A. Multi-factor controls on terrestrial carbon dynamics in urbanized areas. Biogeosciences. 2014;11(24):7107–7124. Available:https://doi.org/10.5194/bg-11-7107-2014
27. Kravchenko AN, Guber AK. Soil pores and their contributions to soil carbon processes. Geoderma. 2017;287:31-39.
28. Li S, Cao Y, Liu J, Wang S, Zhou W. Assessing spatiotemporal dynamics of land use and cover change and carbon storage in China's ecological conservation pilot zone: A case study in Fujian Province. Remote Sensing. 2022;14(16): 4111.
29. Jiang QO, Cheng Y, Jin Q, Deng X, Qi Y. Simulation of forestland dynamics in a typical deforestation and afforestation area under climate scenarios. Energies. 2015;8(10):10558-10583.
30. Rumpel C, Kögel-Knabner I. Deep soil organic matter—a key but poorly understood component of terrestrial C cycle. Plant and Soil. 2011;338(1):143–158. Available:https://doi.org/10.1007/s11104-010-0391-5
31. Chaplot V, Cooper M. Soil aggregate stability to predict organic carbon outputs from soils. Geoderma. 2015;243–244:205–213. Available:https://doi.org/https://doi.org/10.1016/j.geoderma.2014.12.013
32. Sierra CA, Trumbore SE, Davidson EA, Vicca S, Janssens I. Sensitivity of decomposition rates of soil organic matter with respect to simultaneous changes in temperature and moisture. Journal of Advances in Modeling Earth Systems. 2015;7(1):335–356. Available:https://doi.org/Available:https://doi.org/10.1002/2014MS000358
33. Twongyirwe R, Sheil D, Majaliwa JGM, Ebanyat P, Tenywa MM, van Heist M, Kumar L. Variability of soil organic carbon stocks under different land uses: A study in an afro-montane landscape in southwestern Uganda. Geoderma. 2013; 193:282-289.
34. Varik M, Aosaar J, Ostonen I, Lõhmus K, Uri V. Carbon and nitrogen accumulation in belowground tree biomass in a chronosequence of silver birch stands. Forest Ecology and Management. 2013; 302:62-70.
35. Raich JW, Clark DA, Schwendenmann L, Wood TE. Aboveground tree growth varies with belowground carbon allocation in a tropical rainforest environment. PloS One. 2014;9(6):e100275.
36. Xu S, Li P, Sayer EJ, Zhang B, Wang J, Qiao C, et al. Initial soil organic matter content influences the storage and turnover of litter, Root and Soil Carbon in Grasslands. Ecosystems. 2018;21(7): 1377–1389. Available:https://doi.org/10.1007/s10021-018-0227-3
37. Zhang F, Zhan J, Zhang Q, Yao L, Liu W. Impacts of land use/cover change on terrestrial carbon stocks in Uganda. Physics and Chemistry of the Earth, Parts A/B/C. 2017;101:195–203. Available:https://doi.org/10.1016/j.pce.2017.03.005

38. Qu R, He L, He Z, Wang B, Lyu P, Wang J, et al. A study of carbon stock changes in the Alpine Grassland Ecosystem of Zoigê, China, 2000–2020. Land. 2022;11(8):1232.
39. De Rosa D, Ballabio C, Lugato E, Fasiolo M, Jones A, Panagos P. Soil organic carbon stocks in European croplands and grasslands: How much have we lost in the past decade?. Global Change Biology. 2024;30(1):e16992.
40. Jiang M, Li H, Zhang W, Liu J, Zhang Q. Effects of climate change and grazing on the soil organic carbon stock of alpine wetlands on the Tibetan Plateau from 2000 to 2018. CATENA. 2024;238:107870.
41. Bera T, Samui S, Dey A, Ankireddypalli J. Soil carbon sequestration in the context of climate change. In Climate Change Impacts on Soil-Plant-Atmosphere Continuum. Singapore: Springer Nature Singapore. 2024;63-106.
42. Makuma-Massa H, Ochanda D, Nandozi C, Mfutumikiza D, Majaliwa J. Land use change effect on carbon stocks in western Uganda. RUFORUM Institutional Repository. 2014;145–146. Available:http://repository.ruforum.org/documents/land-use-change-effect-carbon-stocks-western-uganda
43. Limpert KE, Carnell PE, Macreadie PI. Managing agricultural grazing to enhance the carbon sequestration capacity of freshwater wetlands. Wetlands Ecology and Management. 2021;29(2):231–244. Available:https://doi.org/10.1007/s11273-020-09780-7
44. Grau HR, Torres R, Gasparri NI, Blendinger PG, Marinaro S, Macchi L. Natural grasslands in the Chaco. A neglected ecosystem under threat by agriculture expansion and forest-oriented conservation policies. Journal of Arid Environments. 2015;123:40–46. Available:https://doi.org/Available:https://doi.org/10.1016/j.jaridenv.2014.12.006
45. Dondini M, Martin M, De-Camillis C, Uwizeye A, Soussana J-F, Robinson T, Steinfeld H. Global assessment of soil carbon in grasslands- From current stock estimates to sequestration potential. FAO Animal Production and Health Paper. 2023;187. Available:http://www.fao.org/documents/card/en/c/cc3981en
46. Morrison EHJ. Ecological restoration of papyrus wetlands at Lake Naivasha, Kenya: Social and Ecological Considerations. 2013;17. Available:https://lra.le.ac.uk/bitstream/2381/28183/1/2013MorrisonEHJMPhD.pdf
47. Austin EE, Wickings K, McDaniel MD, Robertson GP, Grandy AS. Cover crop root contributions to soil carbon in a no-till corn bioenergy cropping system. GCB Bioenergy. 2017;9(7):1252–1263. Available:https://doi.org/Available:https://doi.org/10.1111/gcbb.12428
48. Hussain S, Hussain S, Guo R, Sarwar M, Ren X, Krstic D, et al. Carbon sequestration to avoid soil degradation: A Review on the Role of Conservation Tillage. In Plants. 2021;10(10).
49. Diacono M, Montemurro F. Long-Term Effects of Organic Amendments on Soil Fertility BT - Sustainable Agriculture (E. Lichtfouse, M. Hamelin, M. Navarrete, P. Debaeke (eds.). Springer Netherlands. 2011;2:761–786. Available:https://doi.org/10.1007/978-94-007-0394-0_34
50. Kay S, Rega C, Moreno G, den Herder M, Palma JHN, Borek R, et al. Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. Land Use Policy. 2019;83:581–593. Available:https://doi.org/10.1016/j.landusepol.2019.02.025
51. Bherwani H, Banerji T, Menon R. Role and value of urban forests in carbon sequestration: Review and assessment in Indian context. Environment, Development and Sustainability. 2024;26(1):603-626.

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