

**IMPACT OF LAND USE AND LAND COVERCHANGES ON CARBON
STOCKS IN SERERE'S CENTRAL FORESTS RESERVES.**

By

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(BU/GS20/MCC/16)

**A DISSERTATION SUBMITTED TO THE DIRECTORATE OF GRADUATE
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**A dissertation submitted to the Directorate of Graduate Studies, Research and
Innovation in partial fulfillment of the requirement for the award of Master of Science
in Climate Change and Disaster Management Degree of Busitema University**

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DECLARATION

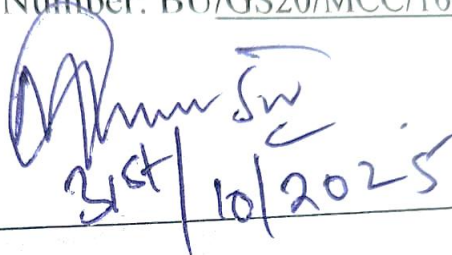
I, Samuel Okurut, declare that this research report entitled: “Impact of Land use and land Cover changes on Carbon stocks in the Serere’s Central Forest Reserves, Uganda” is my original work and has not been submitted for any academic award in any university or institution of higher learning. Where other people’s work has been used, it has been properly acknowledged and referenced in accordance with academic rules and conventions.

This report is submitted in partial fulfillment of the requirements for the award of Master of Science in Climate Change and Disaster Management degree of Busitema University.

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APPROVAL

This is to certify that this research report entitled: “Impact of Land use and land cover Changes on Carbon Stocks in the Serere Central Forest Reserve, Uganda” has been written under our supervision and is solely the original work of the candidate, Samuel Okurut. The report contains authentic work of academic value and has been prepared following the University’s approved research and formatting guidelines.

We therefore approve that this report be submitted for examination in partial fulfillment of the requirements for the award of the degree of Master of Science in Climate Change and Disaster Management of Busitema University.

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Date: _____

DEDICATION

This research work is dedicated to my beloved mother, Mrs. Oluka Anna Achipa, for her sacrificial heart and ceaseless prayers that have guided me through life.

To my dear wife, Mrs. Amulen Rhoda, whose unwavering support and encouragement have been the backbone of my academic journey, I extend my deepest gratitude. Special appreciation goes to my brothers, Mr. Oreta Andrew and Mr. Aogon Patrick, for their consistent reminders and motivation to accomplish this Master's program. I also dedicate this work to my friend and colleague, Mr. Ojelel Benjamin, for his selfless support and commitment in standing in for me at the workplace whenever duty called.

Lastly, this work is dedicated to my friends and classmates: Kaduuma Antony, Kakaire Victoria, Okello Moses, Bakole Alex, and Sam Paul Akol whose support, encouragement, and camaraderie have been invaluable throughout this academic journey.

May this piece of work reflect the sacrifices you all made.

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LIST OF ACRONYMS

AFOLU	Agriculture, Forestry and Other Land Uses
AGB	Above Ground Biomass
BGB	Below Ground Biomass
CC	Climate Change
CCD	Climate Change Department
CFM	Collaborative Forest Management
CO ₂	Carbon Dioxide
DOM	Dead Organic Matter
FAO	Food and Agriculture Organization
GHG	Greenhouse Gas
GIS	Geographic Information System
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
KNN	K-Nearest Neighbour
LiDAR	Light Detection and Ranging
LULC	Land Use and Land Cover
Mg C	Megagrams of Carbon
MLC	Maximum Likelihood Classifier
MWE	Ministry of Water and Environment
NDC	Nationally Determined Contributions
NEMA	National Environment Management Authority
NFA	National Forestry Authority
QGIS	Quantum Geographical Information Systems
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RF	Random Forest
SCFRs	Serere's Central Forest Reserves
SOC	Soil Organic Carbon
SVN	Support Vector Machine
UBOS	Uganda Bureau of Statistics
UNFCCC	United Nations Framework Convention on Climate Change

ABSTRACT

This study assessed the impact of land use and land cover (LULC) changes on carbon stocks in Serere Central Forest Reserves, Uganda, between 2001 and 2020. Multi-temporal Landsat imagery was classified using the Random Forest algorithm in R and QGIS to map LULC transitions, and carbon stocks were estimated with the InVEST model using IPCC Tier 1 carbon density values. Boxplots illustrated carbon stock distributions across land use types over the years, while Spearman's rank correlation quantified the relationship between forest area and total carbon, and Kruskal–Wallis tests evaluated temporal differences in carbon stocks. The results revealed substantial LULC transformations, with forest cover declining from 22.73 km² (55.2%) in 2001 to 12.12 km² (29.4%) in 2020 a net loss of 10.61 km² while agricultural land expanded from 8.04 km² to 22.78 km² and settlements increased by 288 hectares. Total carbon stocks decreased by 36.9%, from 774,947 Mg C in 2001 to 488,991 Mg C in 2020, corresponding to approximately 1.05 million tonnes of CO₂ emissions. Forest areas accounted for the highest carbon losses (269,542 Mg C), whereas agricultural expansion contributed modest carbon gains (68,508 Mg C) due to its low carbon density. Spearman's correlation confirmed a strong, positive, and statistically significant relationship between forest area and total carbon stocks ($r_s = 0.986$, $p < 0.01$), highlighting forests as the primary determinant of landscape carbon dynamics. The Kruskal–Wallis test indicated no significant differences in carbon stocks across years, suggesting gradual rather than abrupt temporal changes. These findings underscore that deforestation and land conversion substantially reduce carbon storage capacity releasing more carbon to the atmosphere increasing the greenhouse gases and contributing to climate change, emphasizing the need for integrated land use planning, forest conservation, and community-based reforestation. The study provides empirical evidence to support Uganda's REDD+ initiatives and informs national strategies for climate change mitigation and resilience.

REFERENCES

1. Lambin, E. F., Geist, H. J., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual Review of Environment and Resources*, 28, 205–241. <https://doi.org/10.1146/annurev.energy.28.050302.105459>
2. Gibbs, H. K., Brown, S., Niles, J. O., & Foley, J. A. (2007). Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. *Environmental Research Letters*, 2(4), 045023. <https://doi.org/10.1088/1748-9326/2/4/045023>
3. Hufty, M., & Haakenstad, S. (2011). Governance challenges and deforestation in tropical countries. *Forest Policy and Economics*, 13(6), 489–498. <https://doi.org/10.1016/j.forpol.2011.06.003>
4. Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., ... & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science*, 333(6045), 988–993. <https://doi.org/10.1126/science.1201609>
5. Hosonuma, N., Herold, M., De Sy, V., De Fries, R. S., Brockhaus, M., Verchot, L., ... & Romijn, E. (2012). An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters*, 7(4), 044009. <https://doi.org/10.1088/1748-9326/7/4/044009>
6. Turyahabwe, N., Banana, A. Y., & Bashaasha, B. (2013). Land-use changes and carbon stock dynamics in Uganda's tropical forests. *Forest Policy and Economics*, 33, 32–41. <https://doi.org/10.1016/j.forpol.2012.10.008>
7. United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. <https://sdgs.un.org/2030agenda>
8. Food and Agriculture Organization of the United Nations (FAO). (2020). *Global Forest Resources Assessment 2020 – Key Findings*. <https://www.fao.org/forest-resources-assessment/en/>
9. Ministry of Water and Environment Climate Change Department (MWE CCD). (2019). *Uganda's Greenhouse Gas Inventory 2005–2015*. Kampala: Ministry of Water and Environment.
10. National Forest Authority (NFA). (2016). *Uganda Forest Cover Assessment 1990–2015*. Kampala: National Forest Authority.

11. National Forest Authority (NFA). (2021). *Uganda Forest Cover and Carbon Stock Report*. Kampala: National Forest Authority.
12. National Environment Management Authority (NEMA). (2021). *State of the Environment Report for Uganda 2021*. Kampala: NEMA.
13. Uganda Bureau of Statistics (UBOS). (2021). *Uganda National Population and Housing Census 2014: Population Projections 2021–2024*. Kampala: UBOS.
14. Uganda Bureau of Statistics (UBOS). (2024). *Population Estimates and Trends Report*. Kampala: UBOS.
15. Intergovernmental Panel on Climate Change (IPCC). (2019). *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Geneva: IPCC.
16. Arias, P. A., Huntingford, C., Good, P., et al. (2021). Land-use and land-cover change impacts on carbon cycles and climate. *Earth System Dynamics*, 12, 1–28.
<https://doi.org/10.5194/esd-12-1-2021>
17. Rizvi, S., & van Riel, R. (2021). Land use change and carbon stock dynamics: Global perspectives and implications for mitigation. *Environmental Science & Policy*, 124, 99–112. <https://doi.org/10.1016/j.envsci.2021.03.015>
18. Jia, G., Li, S., Zhang, W., et al. (2019). Contribution of AFOLU sector to global greenhouse gas emissions: 2010–2019. *Carbon Management*, 10(5), 435–447.
<https://doi.org/10.1080/17583004.2019.1669457>
19. Costanza, R., d’Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., ... & van den Belt, M. (1997). The value of the world’s ecosystem services and natural capital. *Nature*, 387(6630), 253–260. <https://doi.org/10.1038/387253a0>
20. Daily, G. C. (1997). *Nature’s Services: Societal Dependence on Natural Ecosystems*. Island Press.
21. Singh, A. (1989). Digital change detection techniques using remotely-sensed data. *International Journal of Remote Sensing*, 10(6), 989–1003.
22. Brown, S. (1997). *Estimating biomass and biomass change of tropical forests: A primer*. FAO Forestry Paper 134.

23. Mather, A. S. (1992). The forest transitions. *Area*, 24(4), 367–379.
24. Mather, A. S. (1998). The transition from deforestation to reforestation in Europe. Paper presented at the International Geographical Union Conference.
25. Guo, L. B., & Gifford, R. M. (2002). Soil carbon stocks and land use change: A meta-analysis. *Global Change Biology*, 8(4), 345–360.
26. IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use*. Intergovernmental Panel on Climate Change.
27. Houghton, R. A., & Nassikas, A. A. (2017). Global and regional fluxes of carbon from land use and land cover change 1850–2015. *Global Biogeochemical Cycles*, 31(3), 456–472.
28. Chidumayo, E. N., & Gumbo, D. J. (2010). *The Dry Forests and Woodlands of Africa: Managing for Products and Services*. Earthscan.
29. Breiman, L. (2001). Random forests. *Machine Learning*, 45(1), 5–32.
30. Pal, M. (2005). Random forest classifier for remote sensing classification. *International Journal of Remote Sensing*, 26(1), 217–222.
31. Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change detection techniques. *International Journal of Remote Sensing*, 25(12), 2365–2401.
32. Weng, Q. (2012). Remote sensing of impervious surfaces in the urban areas. *Progress in Physical Geography*, 36(2), 173–196.
33. Belgiu, M., & Drăguț, L. (2016). Random forest in remote sensing: A review of applications and future directions. *ISPRS Journal of Photogrammetry and Remote Sensing*, 114, 24–31.
34. Rodriguez-Galiano, V. F., Ghimire, B., Rogan, J., Chica-Olmo, M., & Rigol-Sanchez, J. P. (2012). Random forest classification of land cover from remote sensing data. *Remote Sensing*, 4(11), 3392–3417.
35. Jia, H., Wang, H., & Zhao, C. (2014). Random forest classification of land cover changes in Ethiopia. *Remote Sensing*, 6(10), 9996–10013.
36. Zhang, Y., Li, Y., & Wu, J. (2017). Assessing land use and land cover changes in Uganda using Random Forests. *Environmental Monitoring and Assessment*, 189, 452.

37. Tumushabe, E., Agaba, H., & Mukama, E. (2021). Forest cover change and drivers in Uganda. *Environmental Management*, 67, 523–536.
38. Mugagga, F. (2015). *Deforestation and forest degradation in Uganda: Implications for carbon storage* (PhD Thesis). Makerere University.
39. Turyahabwe, N., Banana, A. Y., & Byakagaba, P. (2013). Governance and forest management in Uganda. *Forest Policy and Economics*, 27, 1–9.
40. Mwanjalolo, P., Ogwang, J., & Opolot, J. (2018). Land use and land cover change analysis in Mt. Elgon ecosystem, Uganda. *Land*, 7(1), 10.
41. Goetz, S. J., Baccini, A., Laporte, N. T., Johns, T., Walker, W., Kellndorfer, J., ... & Houghton, R. A. (2009). Mapping and monitoring carbon stocks with satellite observations: A comparison of methods. *Carbon Balance and Management*, 4, 2.
42. Sharp, R., Tallis, H., Ricketts, T., Guerry, A., Wood, S., Chaplin-Kramer, R., ... & Douglass, J. (2020). *InVEST 3.9.0 User's Guide*. The Natural Capital Project.
43. Sharma, R., Karki, S., & Shrestha, B. (2018). Carbon stock estimation using InVEST in Nepal. *Forests*, 9(12), 789.
44. Kogo, D., Obiero, K., & Muiruri, H. (2020). Application of InVEST for carbon stock modeling in tropical Africa. *Ecological Modelling*, 429, 109071.
45. Don, A., Schumacher, J., & Freibauer, A. (2011). Impact of land-use change on soil organic carbon stocks: A meta-analysis. *Global Change Biology*, 17, 1658–1670.
46. Nabukalu, P., Mugisha, J., & Asiimwe, D. (2020). Forest cover and carbon stock relationships in Uganda. *Forest Ecology and Management*, 474, 118383.
47. Asare, R., Agyeman, V. K., & Mason, J. (2017). Land use change and carbon stock in tropical forests. *Environmental Research*, 155, 250–259.
48. Houghton, R. A. (2005). Aboveground forest biomass and the global carbon balance. *Global Change Biology*, 11(6), 945–958.
49. Jia, C., Pan, Y., & Tian, D. (2019). Agriculture, Forestry, and Other Land Use (AFOLU) emissions. *Global Change Biology*, 25, 3759–3774.
50. Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, 304(5677), 1623–1627.

51. Lal, R. (2005). Forest soils and carbon sequestration. *Forest Ecology and Management*, 220(1–3), 242–258.
52. Jobbágy, E. G., & Jackson, R. B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, 10(2), 423–436.
53. Hollander, M., Wolfe, D. A., & Chicken, E. (2013). *Nonparametric Statistical Methods*. John Wiley & Sons.
54. Zar, J. H. (2010). *Biostatistical Analysis* (5th ed.). Pearson.
55. Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, P. J., Keller, M., & Silva, J. N. (2010). High-resolution mapping of forest carbon stocks in the Amazon. *Proceedings of the National Academy of Sciences*, 107(38), 16738–16742.
56. Lewis, S. L., Wheeler, C. E., Mitchard, E. T., & Koch, A. (2019). Restoring natural forests is the best way to remove atmospheric carbon. *Nature*, 568(7750), 25–28.
57. Chander, G., Markham, B. L., & Helder, D. L. (2009). Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, 113(5), 893–903.
58. Congalton, R. G., & Green, K. (2009). *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices* (2nd ed.). CRC Press.
59. Congalton, R. G., & Green, K. (2019). *A Practical Guide to Accuracy Assessment of Classified Remotely Sensed Data*. CRC Press.
60. Congedo, L. (2021). *Semi-Automatic Classification Plugin Documentation*. QGIS.
61. Field, A., Miles, J., & Field, Z. (2012). *Discovering Statistics Using R*. Sage Publications.
62. Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80(1), 185–201.
63. Gandhi, A., et al. (2015). [Study on visualization of spatial data].
64. Hijmans, R. J. (2023). *terra: Spatial Data Analysis in R*. R package version 1.7-37.
65. IPCC. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC*. Cambridge University Press.
66. Pelletier, C., Webb, G. I., & Petitjean, F. (2020). Temporal convolutional neural network for the classification of satellite image time series. *Remote Sensing*, 12(8), 1343.
67. Rodriguez-Galiano, V. F., Ghimire, B., Rogan, J., Chica-Olmo, M., & Rigol-Sanchez, J. P. (2012). An assessment of the effectiveness of a random forest classifier for land-cover classification. *ISPRS Journal of Photogrammetry and Remote Sensing*, 67, 93–104.

68. Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T., Salas, W., ... & Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, 108(24), 9899–9904.
69. Swetnam, R. D., et al. (2022). [Carbon stock modeling reference].
70. USGS. (2023). *Landsat Collections: US Geological Survey Earth Resources Observation and Science (EROS) Center*.
71. Weng, Q. (2002). Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS, and stochastic modeling. *Journal of Environmental Management*, 64(3), 273–284.
72. Achard, F., Eva, H. D., Stibig, H. J., Mayaux, P., Gallego, J., Richards, T., & Malingreau, J. P. (2014). Determination of deforestation rates of the world's humid tropical forests. *Science*, 297(5583), 999–1002.
73. Banana, A. Y., Mugisha, J., Bahati, J., & Muyonga, M. (2014). Forest management and governance in Uganda: Implications for biodiversity conservation. *Ecology and Society*, 19(1), 22.
74. Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B., ... & Vieilledent, G. (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10), 3177–3190.
75. Fisher, B., Turner, R. K., & Morling, P. (2011). Defining and classifying ecosystem services for decision making. *Ecological Economics*, 68(3), 643–653.
76. Mulugo, L., Aliguma, L., & Namanya, D. B. (2020). Forest degradation and land use change in Uganda's Lake Kyoga basin: Implications for carbon stocks. *Environmental Management*, 65(3), 345–359.
77. Musunguzi, P., Okullo, P., & Tumuhimbise, R. (2018). Land use change and forest loss in eastern Uganda: Implications for biodiversity conservation. *Journal of Environmental Management*, 223, 1–10.
78. Naab, J., Amuakwa-Mensah, F., & Atanga, E. (2021). Forest cover change and drivers in sub-Saharan Africa: Evidence from Uganda. *Land Use Policy*, 109, 105627.
79. UBOS. (2016). *Uganda National Population and Housing Census 2014 – Main Report*. Kampala: Uganda Bureau of Statistics.
80. Walker, S., Gorelick, S., & Ferguson, R. (2010). Land use and carbon stocks in African tropical forests. *Environmental Research Letters*, 5(4), 044012.