Linking Satellite-Derived Biomass and Carbon Stocks to Environmental Drivers in Mangrove Ecosystems Using Machine Learning

Y. Mathivathanan[1], V. Abishethvarman[2*]
[1]*Postgraduate Institute of Science, University of Peradeniya, Peradeniya, Sri Lanka.*
[2]*Department of Computing & Information Systems, Faculty of Computing, Sabaragamuwa University of Sri Lanka, Belihuloya, Sri Lanka.*
*abishethvarman@gmail.com

Mangrove ecosystems represent highly efficient natural carbon sinks, playing a crucial role in climate change mitigation due to their high capacity for biomass accumulation and long-term carbon sequestration. Accurate estimation of mangrove carbon stocks is essential for ecosystem restoration, conservation planning, blue carbon accounting, and supporting national climate commitments. However, accurately estimating mangrove biomass and carbon stocks remains challenging because of limited field accessibility, cost-intensive measurements, and the spatial heterogeneity of coastal environments. This study examines the relationship between satellite-derived remote sensing data and mangrove carbon stocks using machine learning approaches, aiming to enhance predictive accuracy through the integration of ecological and geospatial variables. A dataset comprising 300 observations collected from mangrove ecosystems of Fresco and Sassandra, Côte d'Ivoire (West Africa), was utilized, incorporating field-based measurements of above-ground biomass, below-ground biomass, soil carbon stock, and total carbon stock, along with Sentinel-2 optical bands (B1–B12) and Sentinel-1 radar backscatter variables (VV and VH). The methodological framework involved data preprocessing, feature selection, and the development of two Random Forest regression models: one based solely on satellite-derived variables and another integrating both satellite and ecological features. Model performance was assessed using the coefficient of determination (R^2), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE), and feature importance analysis was conducted to identify key predictors. The satellite-only model demonstrated moderate predictive performance with an R^2 of 0.3359, RMSE of 785.83, and MAE of 464.36, indicating limited explanatory power when relying on remote sensing data. In contrast, the integrated model showed a substantial improvement in performance, achieving an R^2 of 0.9942, RMSE of 73.66, and MAE of 38.89. The enhancement in predictive accuracy underscores the significant contribution of ecological variables, with soil carbon stock emerging as the most influential predictor of total carbon stock which is consistent with previous mangrove carbon estimation studies highlighting the dominant role of soil carbon in blue carbon ecosystems. Among the satellite-derived variables, spectral band B4 and radar backscatter (VH) exhibited moderate importance, suggesting that vegetation reflectance and structural characteristics play a meaningful role in carbon estimation. Overall, the findings demonstrate that while satellite-derived data provide valuable spatial information, its predictive effectiveness is considerably enhanced when combined with ground-based ecological measurements making the proposed approach suitable for large-scale mangrove carbon monitoring and blue carbon assessment. This study highlights the importance of hybrid modeling approaches for ecosystem carbon estimation and offers a scalable framework for improving carbon stock assessment in mangrove forests, thereby supporting conservation planning, restoration initiatives, carbon accounting, and climate policy decision-making. The results contribute to advancing remote sensing-based ecological modeling and support more accurate monitoring of blue carbon ecosystems for climate change mitigation.

Keywords: *Carbon stock estimation, Ecological modeling, Mangrove ecosystems, Remote sensing, Satellite imagery, Vegetation indices*