Blue Carbon Stock Mapping of the Sundarbans Mangrove Ecosystem, Bangladesh (2000–2025): A Hybrid GeoAI Ensemble Framework

S. Zubyer[1,2], M.R Hasan[1,2,*], F.Z. Arabi[1,2]
[1]*Cygnus Foundation, Dhaka, Bangladesh*
[2]*Department of Soil, Water and Environment, University of Dhaka, Bangladesh*
*mdrakib-2019417268@swe.du.ac.bd

The Sundarbans mangrove system constitutes a globally consequential blue carbon sink, yet vertically resolved soil organic carbon (SOC) inventories, particularly at depth, remain under- constrained. This study deployed a geospatial deep-learning pipeline integrating multi-source Earth observation data (optical, SAR, and DEM-derived covariates) to spatially upscale SOC stocks to 1m depth across the Bangladesh Sundarbans. Stratified coring across five sites positioned along the salinity-tidal inundation gradient to represent four major vegetation zones (n=25; one pit per site × five depth intervals: 0-20, 20-40, 40-60, 60-80, 80-100cm) captured physicochemical and SOC attributions. A Kruskal–Wallis test confirmed a positive SOC gradient with depth (H=21.7, df = 4, $p<0.001$); post-hoc Dunn's pairwise comparisons showed 60–100cm layers differed significantly from all shallower layers ($p<0.01$, Bonferroni-adjusted), with the dominant pool residing below 40cm, implying systematic underestimation by conventional shallow-core (≤30–40 cm) assessments. To partition total ecosystem carbon and establish soil-pool dominance, above and belowground biomass were parameterized using species-specific allometric equations, revealing high stem density but comparatively low basal area consistent with a regenerating stand structure dominated by *Heritiera fomes* and *Sonneratia apetala*. Analysis of a previously published Landsat-derived mangrove record (1988–2022) revealed net contraction in mangrove extent; loss-agent raster attribution, based on shoreline-proximity buffers, land-cover transition sequences and cyclone-track coincidence, identified chronic tidal abrasion and erosion as the primary driver rather than anthropogenic conversion or cyclonic disturbance. Benchmarking against a previously published global30m machine-learning SOC product revealed a 4.2 fold underestimation of SOC stocks in the Bangladesh Sundarbans, particularly in peat-enriched, anoxic substrata. Assimilation of deep-profile in situ observations with the pipeline significantly improves spatial prediction fidelity and establishes a robust baseline for Measurement, Reporting, and Verification for greenhouse gas inventories, highlighting the necessity of incorporating deep-soil carbon pools for inventorizing erosion-vulnerable seaward margins.

Keywords: *Bangladesh, Blue carbon, Carbon stock, Deep learning, Geo AI, Sundarbans*