WAT-29 ORAL PRESENTATION · WATER TRACK · REMOTE SENSING, GIS & AI FOR WATER

Land Cover Controls on Thermal-Hydrological Stress: A Differential Evolution-Weighted Ecosystem Index Approach

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DOI: https://doi.org/10.31705/ICEWSE.2026.56

Abstract

Composite ecosystem indices used in water resource and land management planning are typically built with subjectively assigned component weights, undermining their objectivity and cross-basin transferability. This study applies a Differential Evolution (DE) metaheuristic optimization algorithm to objectively derive weights for an Ecosystem Service Index (ESI), fusing InVEST-modelled Habitat Quality, Soil Retention, Normalized Difference Vegetation Index (NDVI), and Sentinel-1 SAR VH backscatter across the Giriulla sub-basin, Sri Lanka. The DE algorithm (50-individual population, 100 generations, 30 runs) was used to search for the weight vector that maximized the negative correlation between ESI and remotely sensed Land Surface Temperature (LST), reflecting vegetation- and soil-water-driven surface energy balance. Applied across three cloud-minimal years (2018, 2020, and 2024), the optimized index produced strong negative correlations with LST (Pearson r = -0.63 to -0.66; Spearman ρ = -0.70 to -0.72), with Soil Retention emerging as the dominant indicator (weight = 0.56). Forest patches sustained the coolest temperatures (25–40 °C) and maintained the highest ESI values, approaching 0.14, whereas urban environments and bare soils exhibited severe ecological suppression, with depressed ESI ranges of 0.08–0.09 and 0.10–0.11, and higher temperatures of 35–50 °C, reflecting land-cover-mediated water and energy exchange. Further, a protected forest reserve (Kegalle Kurulu Kele) recorded ESI of 0.120–0.135 and LST of 32–36 °C, consistent with this basin-wide intact-forest pattern. This remote sensing-based optimization framework offers landscape planners and ecosystem managers a scalable tool for identifying land-cover interventions that most effectively mitigate thermal and hydrological stress across data-scarce tropical basins.

Keywords: *differential evolution; land surface temperature; remote sensing; water-energy balance*