A Hybrid Machine Learning Framework for Predicting Points and Continuous Soil Water Retention in Tropical Soils

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Accurate characterization of soil hydraulic properties, including field capacity (FC), permanent wilting point (PWP), and the complete soil water retention curve (SWRC), is fundamental to sustainable water management and hydrological modeling, particularly in heterogeneous tropical environments. However, direct laboratory measurements are resource-intensive and time-consuming and widely used pedotransfer functions (PTFs) like Rosetta 3 often exhibit limited transferability to tropical soils due to inherent biases in their training data. This study presents a dual-stage computational framework to address these challenges using a sparse, region-specific dataset from Sri Lanka, which was filtered by excluding entries with missing values. First, we develop and validate explainable machine learning (ML) models, demonstrating that ensemble methods such as Random Forest (RF), Extra Trees Regressor (ETR) can accurately predict discrete FC and PWP values ($R^2 > 0.90$, RMSE > 3.0). Second, we introduce a novel, physics-informed neural network (NN) that generates continuous and physically plausible SWRCs. This hybrid model integrates a baseline PTF to enforce physical coherence, while a constrained NN trained on local data, refines the output to prevent implausible predictions. The 5-fold cross-validation was employed for unbiased evaluation. All the developed models were significantly outperforming the Rosetta 3 benchmark ($R^2 < 0.37$) for predicting FC and PWP. This integrated framework provides a cost-effective, accurate method for characterizing soil hydraulic properties from sparse local data, as a viable alternative to global PTFs, enabling advanced modeling and precision agriculture in data-scarce regions.

Keywords: Hydrological modeling, Machine learning, Neural Networks, Pedotransfer functions, Soil water

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