Integration of In Situ Measurements and Multi-Sensor Remote Sensing for Above-Ground Biomass Estimation in High-Mountain Summer Pastures of Azerbaijan

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Abstract

Accurate estimation of above-ground biomass (AGB) in mountainous pastures is critical for sustainable rangeland management. This study develops and evaluates models to predict pasture biomass in the highlands of Azerbaijan using destructively sampled field plots ($n \approx 60$) collected in September 2020 as ground truth. Remotely sensed features were extracted from temporally aligned Sentinel-1 SAR (γ^0_VV_dB, γ^0_VH_dB, VH–VV_dB, RVI) and Sentinel-2 optical imagery (NDVI, NDMI, MSAVI), together with topographic covariates (altitude, slope). Sentinel-1 Level-1 GRD scenes were manually processed in SNAP and Band Math for VH–VV (dB) and RVI (computed in linear domain) calculated afterwords. Sentinel-2 Level-2A data were composited in Google Earth Engine using cloud masking and index derivation; all layers were coregistered at 10 m (UTM 38N). Plot-level predictors were sampled as 7 m-buffer medians to reduce geolocation and mixed-pixel effects. We compared ordinary least squares (OLS) regression and Random Forest (RF), with both raw features and principal-component (PCA) reductions of optical and SAR blocks. OLS achieved an apparent fit up to $R^2 = 0.63$, while RF attained cross-validated $R^2 \approx 0.30$ with RMSE below the recommended 400 kg DM ha^{-1} threshold. Feature importance analyses consistently highlighted altitude and optical indices (NDVI/NDMI/MSAVI) as dominant predictors, with SAR variables providing modest but complementary structural/moisture information, and PCA improving RF stability by reducing multicollinearity. The workflow demonstrates a reproducible, fine-scale (10 m) pathway for integrating in situ measurements with multi-sensor satellite data to map pasture biomass in cloud- and topography-challenged environments.