Determination of Post-Fire Soil Infiltration Using a Hybrid Machine Learning Framework

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Abstract

Wildfires can severely degrade ecosystems and the services they provide, making effective post-fire rehabilitation essential. One important consequence of wildfire is reduced soil permeability caused by increased soil water repellency, which can intensify surface water runoff and erosion. Accurate assessment of post-fire soil condition is therefore critical for evaluating and guiding restoration efforts. Traditional approaches rely on a series of manual experiments to measure water droplet–soil contact angle and water drop penetration time, which serve as indicators of post-fire soil condition and as inputs for modeling infiltration behavior. These experiments are often conducted in remote and difficult-to-access locations, making data collection labor-intensive and time-consuming. In addition, manual measurements are prone to human error. Automated approaches, including drone-based data acquisition and code-based analysis, offer a more efficient and reliable alternative for assessing post-fire soil conditions. As part of a broader effort, this work contributes to the development of an automated analysis framework for video data captured by a drone-mounted camera. A key challenge in estimating water droplet–soil contact angle and penetration time is the accurate identification of the moment when the droplet lands and reaches equilibrium on the soil surface. To address this, we propose a hybrid machine learning model that includes an accurate droplet segmentation model and CNN–BiLSTM–Dense regressor for estimating the equilibrium state through the analysis of frame sequences. The proposed method was evaluated using 140 experiments conducted on a range of soil samples. Its performance was compared with several machine learning approaches using standard error metrics. The results demonstrate that the proposed model achieves high accuracy in estimating the equilibrium state, enabling reliable and automated extraction of droplet-based measurements for post-fire soil assessment and subsequent infiltration modeling.

Keywords: soil water repellency; post-fire soil properties; prediction of water infiltration; machine learning