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Simulating water flow and solute transport at unsaturated soils with unknown initial conditions using physics-informed neural networks trained with time-lapse geoelectrical measurements

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Accurate modeling of water flow and solute transport in unsaturated soils are of significant importance for precision agriculture and environmental protection. However, traditional modeling approaches are considerably challenging since they require well-defined boundaries and initial conditions. Harnessing machine-learning techniques, specifically deep neural networks (DNNs), to detect water flow and solute transport in porous media have recently gained considerable attention [1]. In traditional DNNs, an artificial neural network with several hidden layers is trained solely using data to approximate parameter and state estimation, e.g., the spatiotemporal distribution of water content and pore-water salinity. However, data is extremely limited and sparsely available in subsurface applications. Physics-informed neural networks (PINNs) have recently been developed to learn and solve forward and inverse problems constrained to a set of partial differential equations (PDEs). Unlike traditional DNNs, PINNs are confined to physics and do not require” big” data for training [2]. However, hydrological applications of PINNs only considered an in-silico environment with spatial measurements of hydraulic head, water content and/or solute concentrations well distributed in the subsurface [3]. Such measurements are hard to obtain in real-world applications since they require drilling to extract soil samples or installing in-situ measurement devices at depth which also violets the soil’s natural structure. As opposed to conventional subsurface characterization and monitoring techniques, non-invasive geoelectrical methods can provide continuous, extensive, and non-invasive information of the subsurface [4]. Nevertheless, the sensitivity of the measured electrical signal to various soil parameters, mainly water content and pore-water salinity, as well as inversion errors, could result in biased hydrological interpretations.
This work adopted the PINNs framework to simulate two-dimensional water flow and solute transport during a drip irrigation event and the following redistribution stage, using time-lapse geoelectrical measurements with unknown initial conditions. For that manner, a PINNs system containing two coupled feed-forward DNNs was constructed, describing the spatiotemporal distribution of both water content and pore-water salinity. The system was trained by minimizing the loss function, which incorporates physics-informed penalties, i.e., mismatch with the governing PDEs and boundary conditions, and measurement penalties, i.e., mismatch with the geoelectrical data. Two-dimensional flow and transport numerical simulations conducted with the Hydrus 2D/3D software [5] were used as benchmarks to examine the suitability of the described approach.
Results have shown that the trained PINNs system was able to reproduce the spatiotemporal distribution of both water content and pore-water salinity during both stages, i.e., irrigation and redistribution, with high accuracy, using five time-lapse geoelectrical measurements conducted with 59 electrodes placed at the surface. The trained PINNs system also reconstructed the initial conditions of both state parameters for both stages. It was also able to separate the “measured” electrical signal into its two components, i.e., water content and pore-water salinity. In addition, the subsurface geoelectrical tomograms were significantly improved compared to those obtained from a classical inversion of the raw geoelectrical data.

Participation

In-Person

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