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Using changes in soil moisture to detect CO2 leakage in real-time

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One of the key issues related to geologic CO2 storage is the risk of leakage of both CO2 and brine to the surface. Wellbores are usually the main conduit of CO2 leakage Legacy wells, often remnants of previous oil and gas operations, are particularly problematic because they are abundant in areas targeted for CO2 storage and may fall within the area of review. These wells, if not properly completed or plugged, can serve as pathways for fluids to migrate to the surface or into sensitive subsurface zones. This necessitates the constant monitoring and assessment of legacy wells to ensure they are adequately sealed and do not pose a risk of leakage. Consequently, there is an urgent need for robust and efficient monitoring systems capable of providing early detection of CO2 and brine leakage, which is vital for minimizing both environmental damage and financial repercussions.

Our study aims to address this challenge by designing and implementing a cost-effective near-surface monitoring system that can provide real-time, long-term surveillance of plugged and abandoned (P&A) wells. This system is intended to be both scalable and adaptable, making it suitable for various site conditions and leakage scenarios. To achieve this, we conducted a series of pilot-scale experiments involving controlled releases of CO2 and brine. These experiments were designed to simulate leakage events under a range of conditions, including varying leakage rates and durations. The primary goal was to identify the most sensitive and reliable parameters for detecting fluid migration into vadose zone.
The experiments revealed that soil electrical conductivity (EC) is the most responsive soil signature to CO2 and water leakage. This sensitivity makes EC a valuable parameter for near-surface monitoring systems. By combining EC measurements with advanced data analysis techniques, we were able to improve the accuracy and reliability of leakage detection. Specifically, we integrated a Physics-Informed Neural Network (PINN) model with a supervised classification machine learning algorithm to analyze the data. This hybrid approach allowed us to distinguish between anomalies caused by fluid leakage and those resulting from natural environmental variations, such as changes in soil moisture or temperature. The PINN model provided a framework for incorporating physical principles into the analysis, enhancing the model's ability to interpret complex datasets and predict leakage events with high precision.
Furthermore, the system's ability to operate in real-time and provide continuous monitoring is a significant advantage. Real-time data collection and analysis enable rapid response to potential leakage events, reducing the risk of extensive environmental damage. The long-term surveillance capability ensures that P&A wells can be monitored throughout the lifecycle of a CO2 storage project, providing ongoing assurance of their integrity.
In addition to its technical benefits, the proposed monitoring system is designed to be cost-effective, which is crucial for its widespread adoption in commercial CCS projects. The use of readily available sensors and advanced data processing techniques minimizes operational costs while maximizing efficiency. This makes the system a practical solution for monitoring large numbers of legacy wells, even in resource-constrained settings.

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References

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