MannKaaval: A Framework for Detection and Monitoring of Sand Mining Using Interpretable Machine Learning and Causal Inference

Sivakumar, Ashwanth (School: CPS Global School)

According to UNEP, Sand is the most mined solid natural resource in the world, with up to 50 billion tons used annually. This high demand results in unmonitored illegal mining. It is a $350 billion enterprise linked to 618+ reported deaths and irreversible ecological damage, including groundwater depletion and the endangering of endemic species. Current monitoring systems are sporadic, while existing deep learning detection models are highly resource-intensive and produce black-box predictions. To address this gap, Mannkaaval, a novel near real-time machine learning satellite framework was developed. 39 spatiotemporal variables across ~240 mining sites and ~390 non-mining sites, listed in the India Sand Watch repository, were extracted from Sentinel-2 optical satellite imagery. Using an 80/20 spatial blocking split, an XGBoost model was trained on data augmented with 15% Gaussian noise. When tested, the model yielded an F1 score of 0.95 on the clean test set and 0.86 on the test set with 30% Gaussian noise. To overcome the opacity of traditional deep learning models, Mannkaaval incorporates SHAP-based attribution to explain why a site is flagged. Furthermore, Synthetic Control Analysis is leveraged to quantify the potential environmental harm and monitor recovery efforts. These features are integrated, with a risk probability grid, into a dashboard, providing a near-real-time monitoring system that transforms raw data into transparent evidence for immediate environmental conservation. The Mannkaaval framework offers an effective, interpretable, and scalable tool to combat illegal sand mining across countries, with broader applications in natural resource monitoring, supporting SDG 15.

Awards Won:

Zydus Pharmaceuticals USA Inc.: First Place Earth and Environmental Sciences