AI-DRIVEN PROBABILISTIC INSTABILITY MONITORING OF AGRICULTURAL GULLIES USING UAV LiDAR GEOMETRY AND IN-FIELD SOIL MOISTURE SENSING

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INTRODUCTION & OBJECTIVES

Gully erosion threatens soil sustainability in Mediterranean olive orchards, accelerating soil loss and sediment delivery to downstream infrastructure. Despite growing deployment of soil-moisture probes on farms, these data streams are rarely converted into **operational instability indicators for gully banks**.

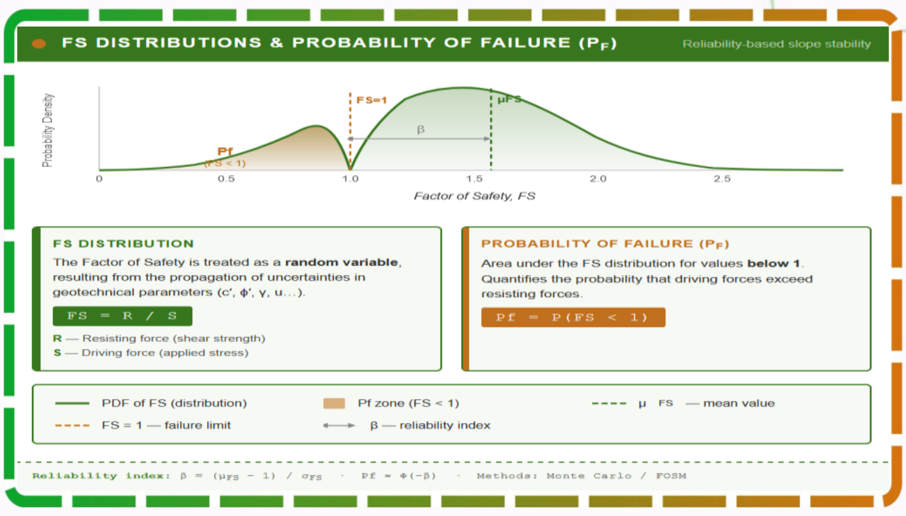
This work develops an **AI-driven data-fusion pipeline** combining UAV LiDAR geometry with continuous soil-moisture sensing to produce interpretable, probabilistic instability indicators for early warning and prioritised field inspection in agricultural gullies.

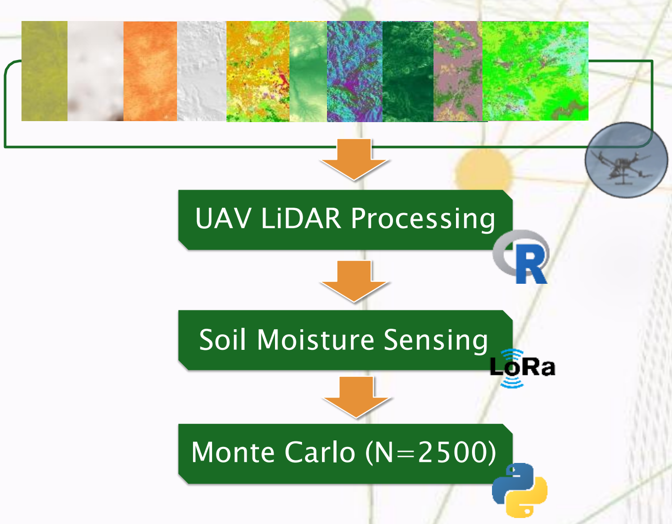
METHODOLOGY

① **UAV LiDAR point clouds** → classified DTM + cross-sections every 5 cm → bank slope, relief, curvature & morphological variability descriptors.

② **In-field soil-moisture sensing**: 4 probes at 15 cm from rim, depths 20-40-60-80 cm (both margins). On-site meteorological station (hourly rainfall, temperature, humidity). Automated QC, gap handling and feature generation.

③ **Probabilistic stability model**: infinite-slope surrogate driven by deep soil moisture (80 cm) as proxy for pore-pressure. Monte Carlo (N=2,500) propagating uncertainty in mobilised depth, strength and unit weight to generate FS distributions and probability of failure (Pf). Event-based alert levels aligned with I-D thresholds.



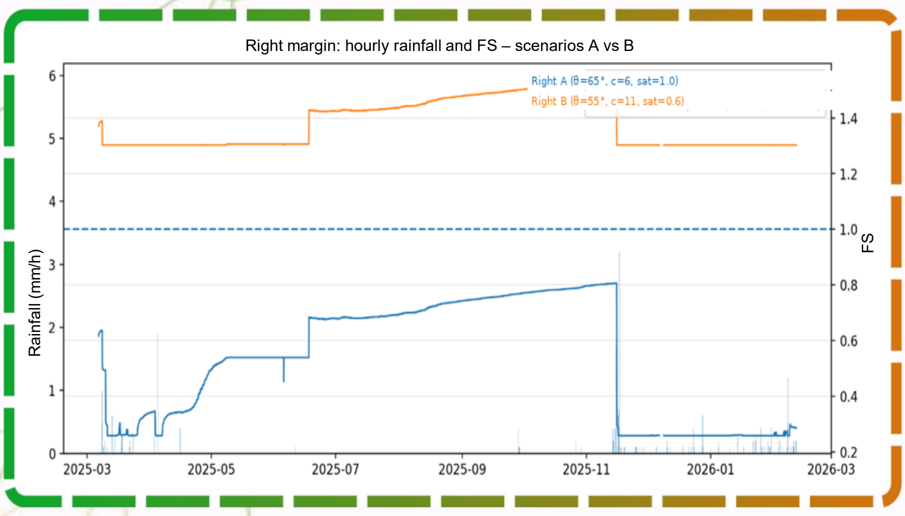


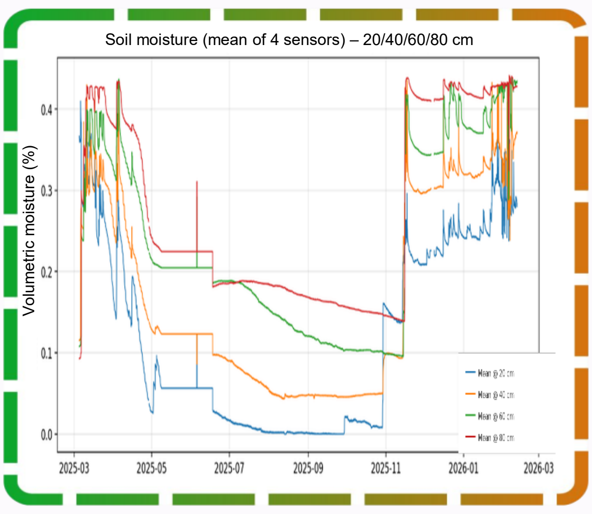
RESULTS & DISCUSSION

The monitoring system revealed **strong asymmetry between margins**. The LiDAR-derived steeper right bank concentrated all instability sensitivity.

- **Scenario A (conservative)**: Right margin Pf ≈ 0.98 | Left margin Pf ≈ 0.76. Full saturation + low cohesion. FS < 1 confirmed in high-moisture periods.
- **Scenario B (realistic)**: Right margin Pf ≈ 0.20 | Left margin Pf ≈ 0. Partial saturation + apparent vegetation cohesion (roots). Realistic field conditions substantially reduce overestimated risk.

Deep soil moisture (80 cm) was the key predictor of FS evolution, outperforming peak rainfall — it integrates antecedent wetness, storage capacity and drainage lag. Time series of FS and Pf clearly highlight windows for targeted inspection after wet periods.





CONCLUSIONS

- UAV LiDAR geometry and continuous soil-moisture sensing can be integrated by AI workflows into interpretable, probabilistic instability indicators suitable for field operations.
- Strong margin asymmetry confirmed: the steeper bank concentrates instability sensitivity, with Pf approaching 1 under conservative assumptions (Scenario A).
- Under realistic conditions (Scenario B: partial saturation + apparent vegetation cohesion), Pf decreased to 0.20 on the critical margin and ~0 on the opposite.
- Deep soil moisture (80 cm) explains risk evolution better than rainfall peaks alone — it acts as integrator of antecedent wetness and pore-pressure evolution.
- The framework supports prioritised inspections, scenario testing (drainage, slope reshaping, vegetation management) and transfer to additional gullies.

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