Session NH3.8 | Landslide monitoring: recent technologies and new perspectives
EGU General Assembly 2023

HYDRO-GEOTECHNICAL MONITORING IN DRY-STONE WALL TERRACES FOR THE INVESTIGATION OF RAINFALL-INDUCED LANDSLIDES: PRELIMINARY RESULTS FROM THE UNESCO WORLD HERITAGE SITE OF THE CINQUE TERRE

Giacomo Pepe[1], Andrea Vigo[1], Andrea Mandarino[1], Emanuele Raso[2], Francesco Marchese[2], Diego Di Martire[3], Giacomo Russo[3], Luigi Guerriero[3], Patrizio Scarpellini[2], Marco Firpo[1], Domenico Calcaterra[3], Andrea Cevasco[1]*

*[1]University of Genoa, Department of Earth, Environmental and Life Sciences (DISTAV), Italy (*giacomo.pepe@unige.it) - [2]Cinque Terre National Park, Riomaggiore, La Spezia, Italy - [3]Department of Earth, Environmental and Resource Sciences (DiSTAR), Federico II University of Naples, Italy*

1 - BACKGROUND & ISSUES

Dry-stone wall terraces are among the most ancient and widespread agricultural practices on hilly-mountainous landscapes (Fig. 1a-b). Their historical, architectural, and environmental value has been recognized worldwide. Recently, "the art of dry-stone walls" was inscribed on the UNESCO Representative List of the Intangible Cultural Heritage of Humanity (Fig. 1c).

Fig. 1 (a-b) Terraced slopes along the coast of Cinque Terre (Italy); (c) dry-stone walls construction activities.

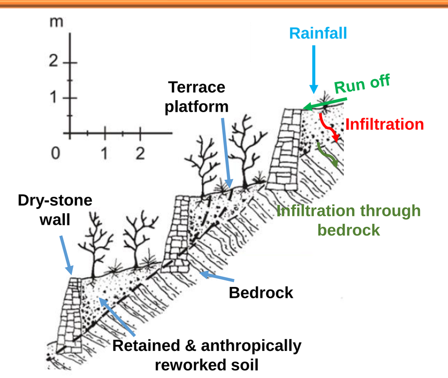


Fig. 2 Hydro-geomorphological functions of terraces (mod. from Cevasco et al. 2014).

Hydro-geomorphological functions of terraces (Fig. 2):

(i) slope reduction

(ii) water infiltration & soil moisture increase

(iii) runoff mitigation

Due to ***abandonment & lack of maintenance***, terraces may progressively lose their hydro-geomorphological functions (Fig. 3).

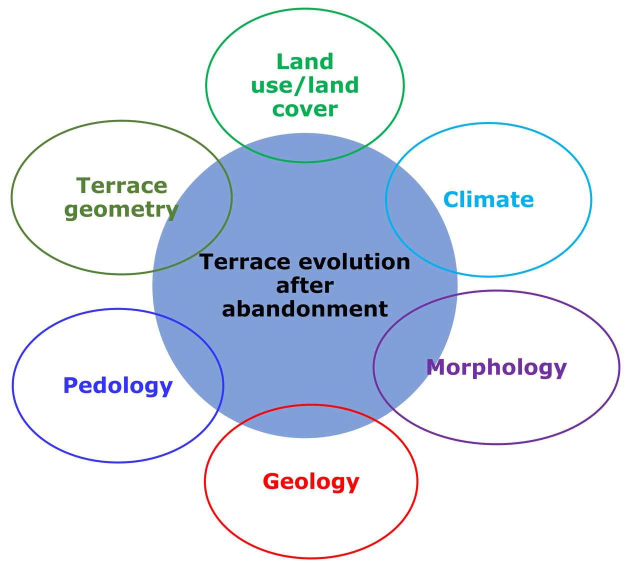


Fig. 6 Factors that can influence the hydro-geomorphological response of terraces after abandonment (adapted from Moreno-de-las-Heras et al. 2019)

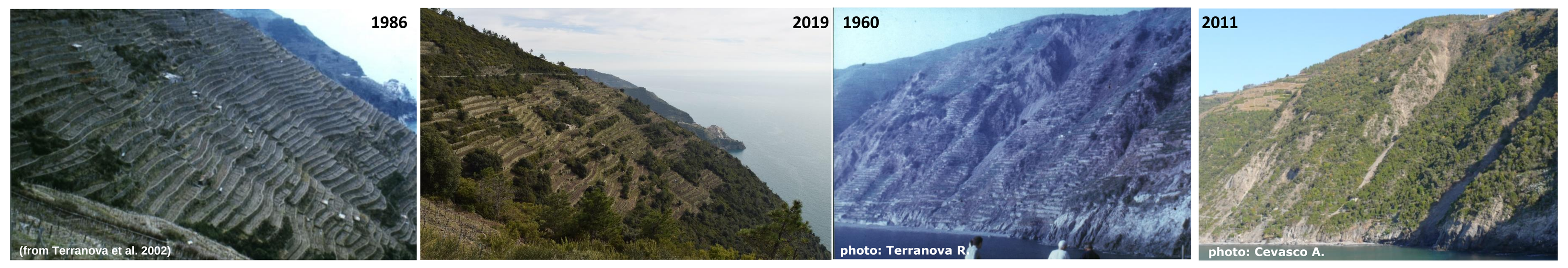


Fig. 3 Examples of terrace evolution following abandonment in Cinque Terre (Italy).

Terrace abandonment is accompanied by ***erosion and mass movements***, which can lead to slope degradation (Fig. 5).

Several factors affect the hydro-geomorphological response of terraced systems after abandonment (Fig. 6).

Fig. 5 Different response to intense rainfall of terraced slopes with different land use/land cover.

2 - RESEARCH PURPOSES & STUDY AREA

The research activities described are in the framework of the a LIFE EU-project ***"STONEWALLSFORLIFE" (S4L)***, which is aimed at investigating the role of dry-stone walls in increasing the resilience of rural areas and in counteracting the impacts of climate change (Fig. 7).

The S4L terraced pilot site (12.5 ha) surrounds the Manarola hamlet (E Liguria, NW Italy), at the outlet of the small V-shaped Groppo valley (Cinque Terre National Park) (Figs. 8-9).

Fig. 7 STONEWALLSFORLIFE (S4L) Project.

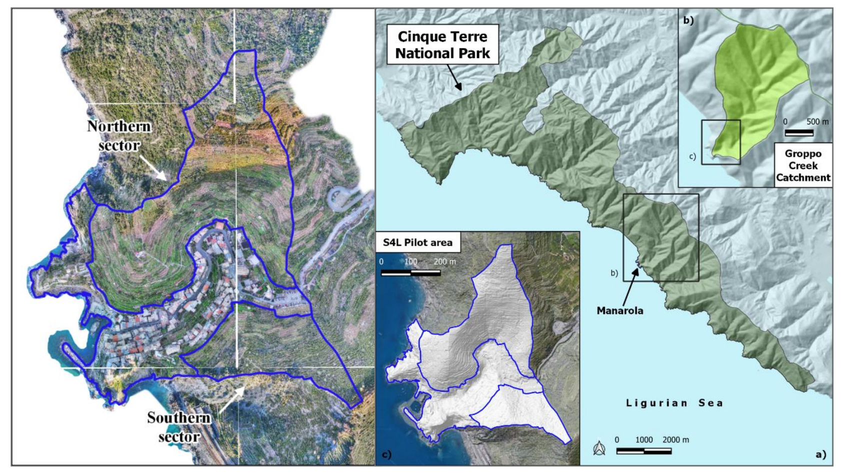


Fig. 8 Location & geomorphological setting of the S4L Project pilot site.

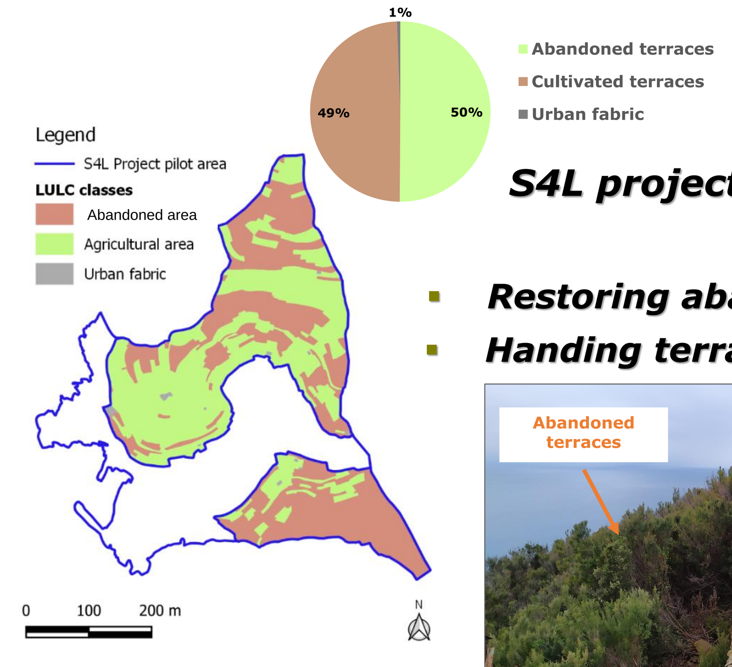


Fig. 9 LULC map of the S4L Project pilot site (Manarola hamlet, Cinque Terre).

S4L project objectives

- ***Restoring abandoned terraces***, making them more resilient also with innovative techniques;
- ***Handing terraces over for productive use*** with long-term contracts to farmers who commit to their ***maintenance***.

Fig. 10 Examples of abandoned and cultivated terraces at the S4L Project pilot site.

Research purposes

- Explore the ***effects of land use*** & of ***management practices*** of dry-stone wall terraces.
- Investigate the ***hydro-geotechnical behaviour*** of dry-stone wall terraces in different ***land use conditions*** & ***state of management*** (Fig. 10).

3 - METHODOLOGICAL FRAMEWORK

Monitoring scenarios & systems

Monitoring scenarios (Figs. 11-12) based on:

- Land use/land cover conditions
- Dry-stone wall management practices

Fig. 11 Overview of the selected monitoring sites (yellow dashed polygons).

Fig. 12 Abandoned & restored terraced sites (vegetation removed); b) cultivated site.

Monitoring scenarios

1. Cultivated terrace (site 2)
2. Abandoned terrace (site 3)
3. Restored terrace & dry-stone walls using traditional building techniques (site 1)
4. Restored terrace & dry-stone walls using innovative/alternative interventions and/or techniques (site 1)

Field & laboratory investigations

Multidisciplinary approach (Figs. 14-15)

(i) geophysical surveys

(ii) GNSS surveys

(iii) geological & geomorphological field surveys

(iv) in situ & laboratory geotechnical tests

(v) shallow test pits

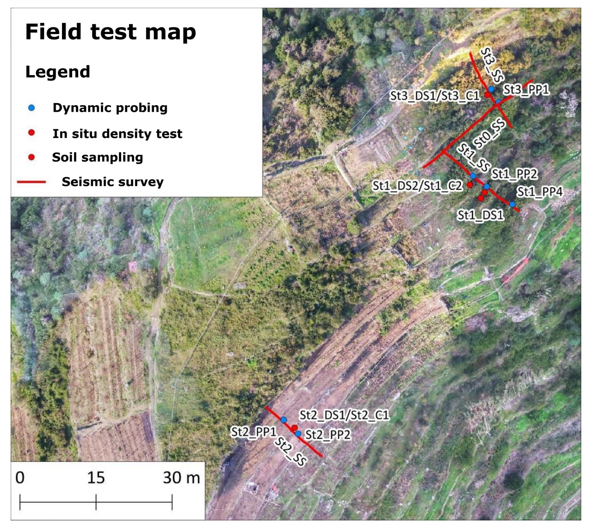


Fig. 14 Site investigation map.

Fig. 15 Field (a-b) and laboratory (c) investigations.

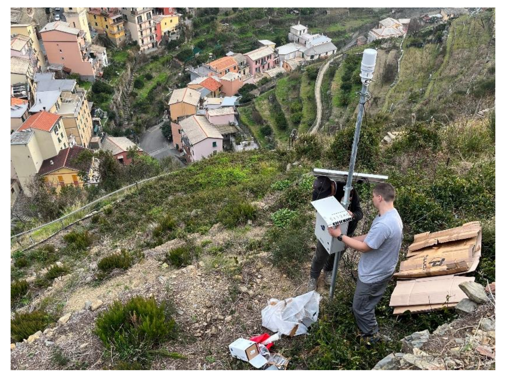


Fig. 16 Weather station installation.

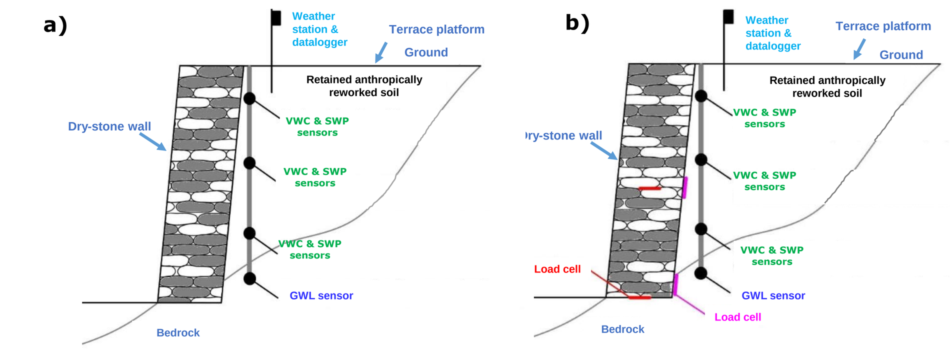


Fig. 13 Multi-parameter monitoring equipment according to the different selected scenarios: (a) cultivated and abandoned terrace; (b) restored terrace & dry-stone walls using traditional and alternative building techniques.

Multi-parametric monitoring stations (Fig. 13)

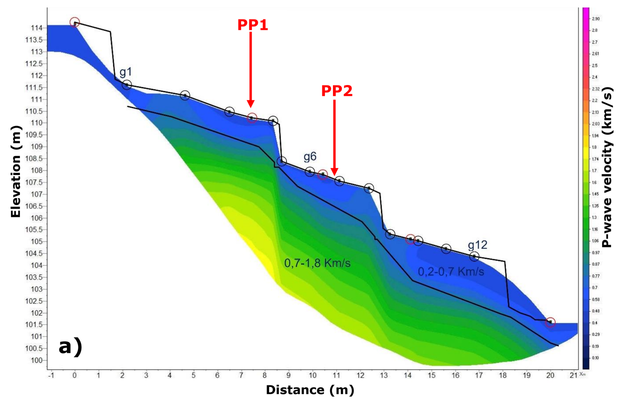
- Dry-stone wall sensors: total stress cells
- Soil sensors: volumetric water content (VWC - TEROS 11, METERGroup 2022a), soil water potential (SWP - TEROS 21, METERGroup 2022b), water-table level (GWL - TE-TL-700)
- Weather sensors: air temperature, relative humidity, global radiation, atmospheric pressure, rainfall, wind speed & direction (Fig. 16)

4 – FIRST RESEARCH ACTIVITIES & PRELIMINARY RESULTS

Monitoring sites engineering-geological characterization

Field and laboratory investigations revealed that along the selected slope sections soil deposits show thickness from 1,0 to 1,5 m and are from loose to medium dense (Fig. 17).

Slope materials are made up of poorly sorted silty gravels & silty sands with low plasticity (Fig. 18 & Table 1).



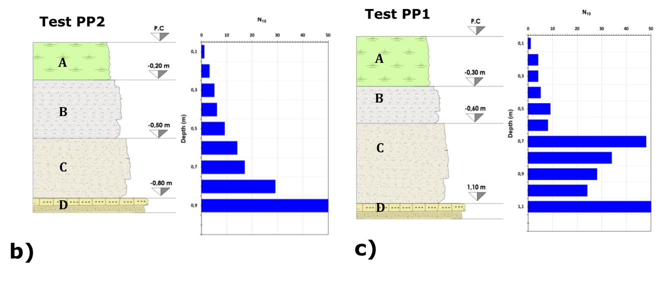


Fig. 17. Representative in situ investigation results: (a) P-wave seismic refraction tomography profile; (b-c) dynamic penetration profiles (N_{10} vs. depth).

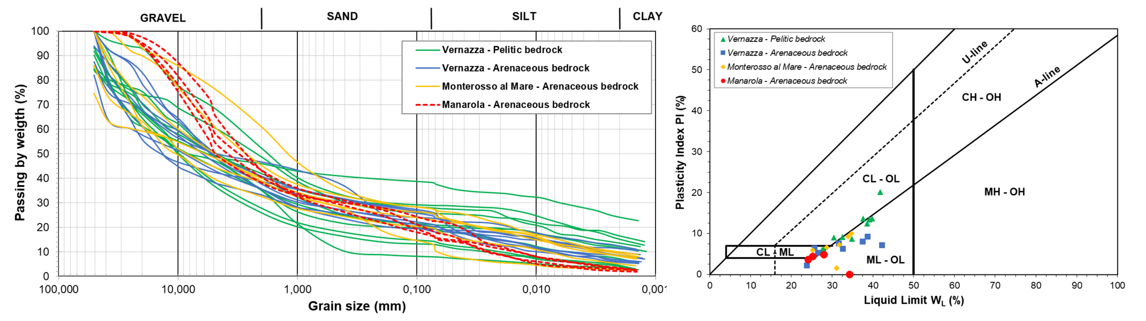


Fig. 18 Grain size and plasticity properties in comparison with other soils collected in the Cinque Terre National Park (data source: Cevasco et al. 2014).

ID	G %	S %	M %	C %	C_u	D_{50} mm	U.S.C.S	W_l %	W_p %	IP %	γ_n kN/m³	γ_d kN/m³	γ_{sat} kN/m³	G_s	n	O.C. %	S_r %
1	50,7	26,8	19,4	3,1	400	4,75	GM	28,0	23,1	4,9	12,5	12,0	17,2	2,587	0,52	6,0	10,2
2	46,3	36,7	14,9	2,1	212	4,0	SM	34,3	n.d.	n.d.	14,0	13,3	18,4	2,825	0,51	10,0	13,9
3	35,4	48,1	13	3,6	308	2,7	SM-SC	25,3	20,8	4,5	14,9	14,6	19,1	2,755	0,46	4,4	7,2
4	42,6	38,9	15,7	2,9	189	3,0	GM	24,2	20,6	3,6	15,9	15,3	19,5	2,740	0,43	3,4	14,4

Tab. 1 Summary of physical soil properties determined from geotechnical laboratory and in situ tests.

n porosity
w_l liquid limit
w_p plastic limit
S_r saturation degree
O.C. organic content
γ_n natural unit weight
γ_d dry unit weight
γ_{sat} saturated unit weight
G_s specific gravity of solids
PI plasticity index
G gravel content
S sand content
M silt content
C clay content
C_U coefficient of uniformity
D_{50} Median particle size

The combination of in-situ and laboratory investigations allowed to define 2-D engineering-geological models across the monitoring site (Fig. 19).

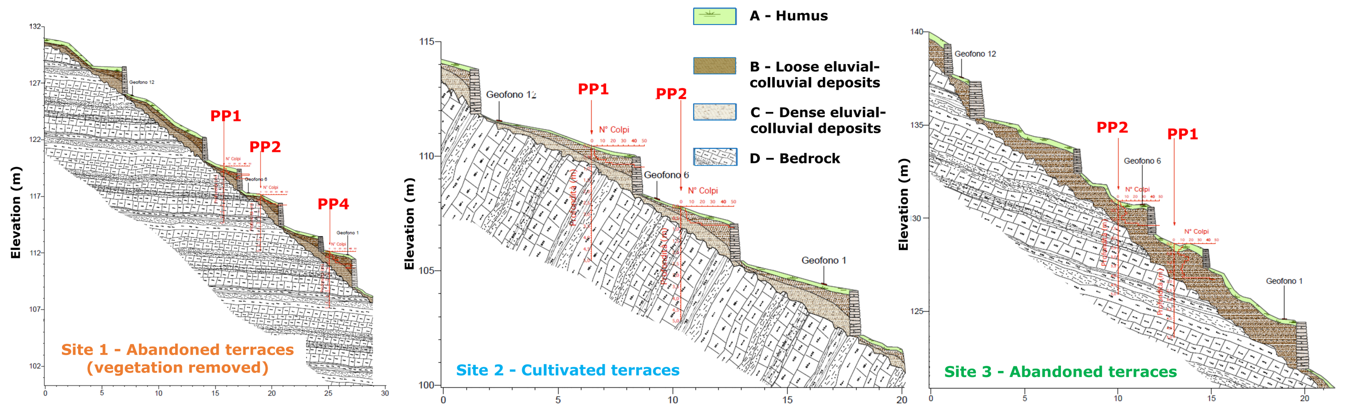


Fig. 19 Engineering-geological 2D-models across the monitored slope sections.

Hydro-geotechnical monitoring

Currently, two monitoring stations have been installed & are actively working. VWC & SWP sensors were positioned at three different depths in undisturbed soil layers within a trench pit and were connected to a datalogging system (Fig. 20).

GWL sensors were positioned into piezometer tubes installed into boreholes (Fig. 20).

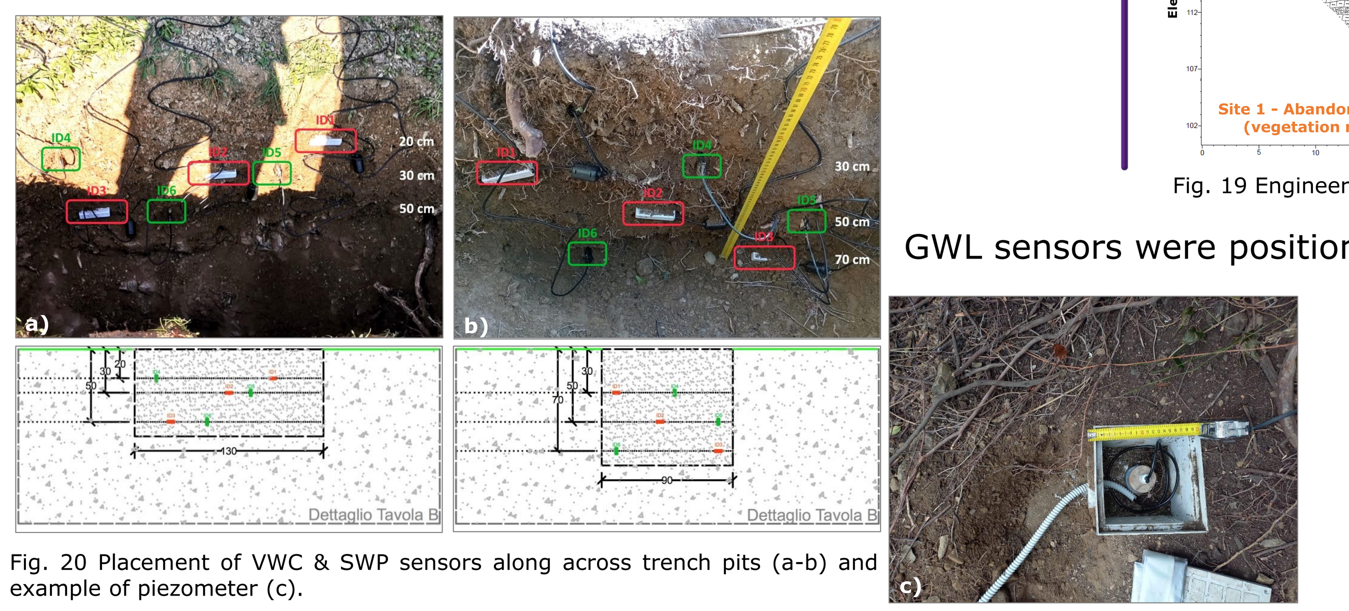


Fig. 20 Placement of VWC & SWP sensors along across trench pits (a-b) and example of piezometer (c).

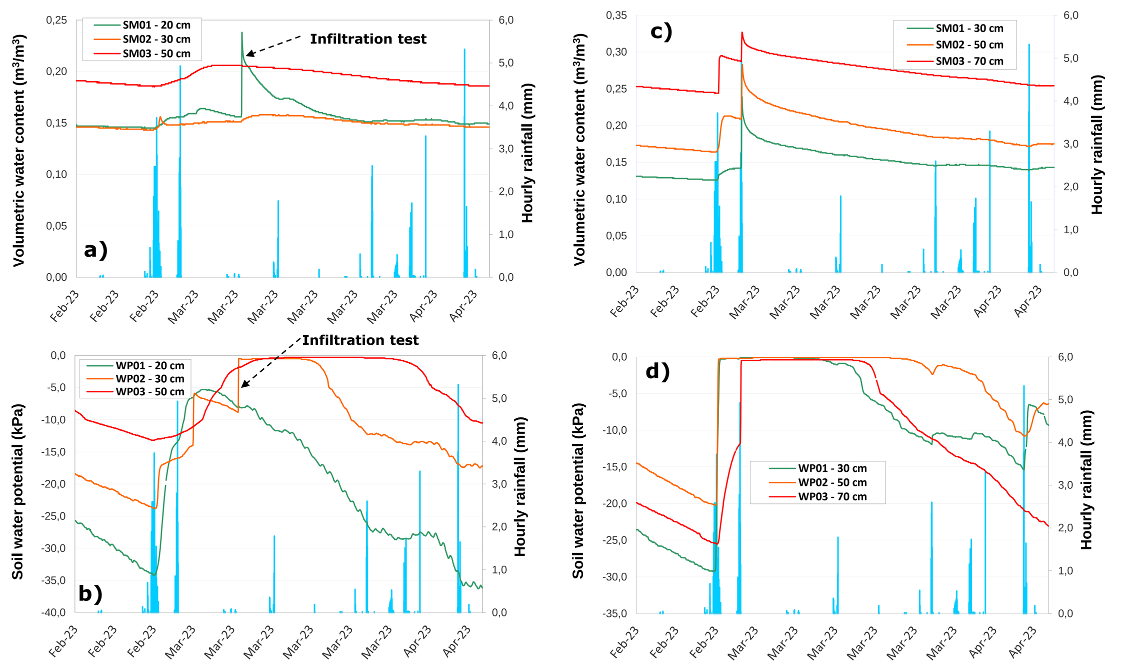


Fig. 21 VWC & SWP sensor data versus cumulative hourly rainfall for the monitoring stations installed at cultivated (a-b) & abandoned terraced sites (c-d).

The availability of approximately two months of monitoring data has made it possible to preliminary analyse the variation of the hydraulic parameters of the terraced soils (Fig. 21).

These data series make it possible to infer some preliminary considerations on the hydraulic response of the soil in the two land use settings.

Both soil moisture and matrix suction sensors reveal a short-term response to rainfall peaks, despite no significant rainfall events were still recorded. However, different behaviours according to depth were observed.

5 - FINAL REMARKS & FUTURE DEVELOPMENTS

From the whole set of investigations, it is expected to improve the knowledge concerning the hydrological processes occurring in dry-stone wall terraces and to obtain useful information for modelling soil mass movements (e.g., shallow landslides), along with indications for the development of effective land management strategies. In the next future, eight total pressure cells will be installed either immediately behind and inside the body dry-stone walls to measure and monitor loads acting on retaining structure.

REFERENCES

- Cevasco A, Pepe G, Brandolini P (2014) *The influences of geological and land use settings on shallow landslides triggered by an intense rainfall event in a coastal terraced environment.* Bull Eng Geol Env **73**:859–875.
- METER Group (2022a) Teros 11 Manual. https://www.metergroup.com/en/meter-environment/products/teros-11/teros-11-tech-specs
- METER Group (2022b) Teros 21 Manual. https://www.metergroup.com/en/meter-environment/products/teros-21/teros-21-tech-specs
- Moreno-de-las-Heras M, Lindenberger F, Latron J, Lana-Renault N, Llorens P, Arnáez J, Romero-Díaz A, Gallart F. (2019) *Hydro-geomorphological consequences of the abandonment of agricultural terraces in the Mediterranean region: Key controlling factors and landscape stability patterns.* Geomorphology **333**: 73-91.

Sharing is encouraged