Cultural landscapes for water management
A research work plan

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Abstract. Dry-stone walls and terraces are typical features of the Mediterranean landscape. Traditional knowledge suggests they might have been constructed to satisfy agricultural water requirements. However, only few studies have tried to quantify their effects on soil moisture in agricultural fields, suggesting deteriorating conditions when maintenance is lacking. This is the case of the Mediterranean region, as a consequence of changes of the social and economic systems. The research work plan outlined here aims to improve scientific understanding of the functioning of terraces and dry-stone walls and quantify their potential for water harvesting and management. In particular, the following aspects will be investigated: (i) modifications of stocks and volatility of soil moisture due to terracing, and its effect on catchment-scale water partitioning; (ii) water yields and water-saving performance of dry-stone walls, and their contribution to water budgets in semi-arid regions; (iii) design innovation required to cope with changes of the climate (e.g., building features, distance among structures); (iv) economic value of services (e.g., water harvesting and hazard mitigation) provided by terraces and dry-stone walls and ways to establish payments for these services. Findings of this project will lay the foundation for a large scale restoration of cultural landscapes aimed at counteracting water scarcity and buffering the effect of climate change in the Mediterranean basin.

Keywords. Terraces - Dry-stone walls - Water harvesting - Dew - Streamflow dynamics - Flood hazard - Budyko model - Isotopes.

Title. Paysages culturels pour la gestion de l'eau. Un plan de travail de recherche

Résumé. *Les murs et les terrasses en pierre sèche sont des caractéristiques typiques du paysage méditerranéen. Les connaissances traditionnelles suggèrent qu'elles pourraient avoir été construites pour satisfaire les besoins en eau des exploitations agricoles. Cependant, seules quelques études ont tenté de quantifier leurs effets sur l'humidité du sol dans les champs agricoles, suggérant une détérioration des conditions lorsque la maintenance fait défaut. C'est le cas de la région méditerranéenne, conséquence des changements des systèmes sociaux et économiques. Le plan de travail de recherche décrit ici vise à améliorer la compréhension scientifique du fonctionnement des terrasses et des murs en pierre sèche et à quantifier leur potentiel de récupération et de gestion de l'eau. Les aspects suivants sont notamment examinés: (i) les modifications des stocks et la volatilité de l'humidité des sols dues au terrassement, et leurs effets sur la répartition de l'eau par bassin versant; ii) les rendements en eau et les performances d'économie d'eau des murs en pierre sèche, ainsi que leur contribution au bilan hydrique dans les régions semi-arides; (iii) l'innovation de conception nécessaire pour faire face aux changements climatiques (par exemple, caractéristiques des bâtiments, distance entre les structures); (iv) la valeur économique des services (par exemple, la récupération de l'eau et l'atténuation des risques) fournis par les terrasses et les murs en pierres sèches, ainsi que des moyens d'établir des paiements pour ces services. Les résultats de ce projet jetteront les bases d'une restauration à grande échelle de paysages culturels visant à lutter contre la pénurie d'eau et à atténuer les effets du changement climatique dans le bassin méditerranéen.*

Mots-clés. *Terrasses - Murs en pierres sèches - Récupération de l'eau - Rosée - Dynamique des débits - Risque d'inondation – Modèle Budyko - Isotopes.*

I - Introduction

The broad Mediterranean region is facing important social and environmental challenges. Rainfall events characterized by reduced duration and increased intensity reveal the ongoing climatic changes and result in natural hazards affecting populations (EU, 2011). Rural areas have been abandoned as a consequence of modifications of the social and economic structures, and the growing risk of water scarcity threatens to intensify depopulation of farmlands and migration (IPCC, 2019). In this context, a deeper understanding of the unfolding changes of the hydrological cycle is needed to ensure safety and early warning of populations and sustainable use of scarce water resources. The need to move beyond a view focused on blue water (i.e. rivers, lakes and groundwater), on which global water policies are still grounded, is manifest (Rockström and Falkenmark, 2015). The renaissance that traditional green-water practices aimed at soil conservation (i.e. subsurface water storage in soils) is experiencing, and the rising number of novel technologies to harvest atmospheric water, hint at the high expectations existing for these alternative approaches to water supply and management in arid regions. Archeological findings (Laureano, 2001) and agricultural practices suggest the efficacy of terracing and dry-stone walling as a measure to increase soil wetness and provide water for agriculture. However, a clear understanding and quantitative assessment of the modifications to the terrestrial part of the hydrological cycle operated by these man-made structures are lacking. The few studies that tried to quantify the effect of terraces and dry-stone walls on soil moisture in the surrounding lands (e.g., Gallart *et al*., 1994; Georgiadis *et al*., 2014) suggest a decline of their reliability when these traditional landscapes are not properly maintained, as is the case for most of the Mediterranean region.

This contribution outlines a research proposal which aims to enhance scientific understanding of the functioning of terraces and dry-stone walls and quantify their potential for large-scale water harvesting and management. The project intends to lay the scientific foundation for a large scale restoration of cultural landscapes aimed at counteracting water scarcity and buffering the effect of climate change in the Mediterranean basin.

II - Research questions

The contribution of cultural landscapes to harvesting and management of water resources in water scarce areas of the Mediterranean will be studied with a focus on two types of man-made structures characterizing the landscape of the region: agricultural terraces and dry stone walls.

WP1: Field-scale modifications of water balance due to cultural landscapes.

(1.1) How efficient are dry-stone walls in supplying water through condensation of atmospheric humidity and in stabilizing soil moisture in agricultural fields?

(1.2) What is the effect of terracing on stocks and volatility of soil moisture at field-scale, available water storage and groundwater recharge, hydrologic pathways and connectivity?

WP2: Large-scale contribution of cultural landscapes to water budgets of catchments in semi-arid regions.

(2.1) What is the overall contribution of atmospheric water condensation on (or favored by) dry-stone walls to the water budget of agricultural areas?

(2.2) What is the effect of terracing on the volatility of river flows and the related character of floods in broadly-terraced watersheds?

WP3: Landscape design innovations required to buffer the effect of climate change and counteract water scarcity.

How should attributes (e.g., size, building features, distance among structures, area coverage) of terraces and dry-stone walls (Figure 1) be updated to optimize soil water conservation and reduce hazard linked to streamflow volatility?

WP4: Economic evaluation and conception of mechanisms to establish payments for landscape services.

(4.1) What is the economic value of specific services (e.g., water saving and harvesting, hazard mitigation) provided by terraces and dry-stone walls?

(4.2) How can payments for these landscape services be established? What conditions of the local social structure support long-lasting and effective restoration?

Figure 1. Dry-stone walls (a) and terraces (b). Select building features are highlighted in blue. According to traditional construction techniques, larger stone sides face the outer part of walls (a). Different heights and widths of agricultural terraces determine the root zone and the volume available for water storage (Photo: Stefano Basso).

III - Methods

Research questions stated above will be addressed with synergistic lab, field and modeling investigations, focusing on typical environmental conditions of semi-arid catchments. A summary of the planned methods is given in the following.

WP1: Field-scale modifications of water balance due to cultural landscapes.

(1.1) Dry-stone walls:

- Analysis of the isotopic signatures of water collected in select field sites to distinguish between rainfall and dew (Figure 2a);
- Field surveys of soil wetness by means of both Electrical Resistivity Tomography and Time-Domain Reflectometry.

(1.2) Terraces:

- Field surveys of soil moisture dynamics and subsurface properties (by means of acoustic or electromagnetic methods) to identify underground discontinuities in terraced fields;
- Comparison of findings and conceptualization of hydrological processes to those recently obtained by studies in areas featuring sub-humid climatic conditions (Preti et al., 2018).

WP2: Large-scale contribution of cultural landscapes to water budgets of catchments in semi-arid regions.

(2.1) Dry-stone walls:

- Mapping of networks of walls in select watersheds through remote sensing (e.g., Lidar) and participatory approaches;
- Water yield and saving rates obtained in WP1.1 will be scaled up to estimate the contribution of extended networks of dry-stone walls to the water budget of agricultural areas.

(2.2) Terraces:

- The Budyko framework (Budyko, 1961) will be adopted to study the effects of terraces on catchment-scale water partitioning (Figure 2b);

- A low-dimensional mechanistic-stochastic model of streamflow dynamics (Basso *et al*., 2015) will be applied to pristine and terraced watersheds subject to same climatic conditions; changes to its physically-meaningful parameters will be identified.

WP3: Landscape design innovations required to buffer the effect of climate change and counteract water scarcity.

(3.1) Dry-stone walls:

- Dew yields from dry-stone walls with different structural features will be studied through laboratory experiments; findings will be formulated according to an existing simplified model of dew generation (Beysens, 2016);
- The model of dew generation will be applied by combining sets of different climatic conditions and structural features, with the aim of highlighting structures providing best performance under modified climatic settings.

(3.2) Terraces:

- The low-dimensional mechanistic-stochastic model of streamflow dynamics developed in WP2.2 will be coupled to the Budyko framework to understand catchment-scale water partitioning under changed climatic conditions;
- Contrasting the response of pristine and terraced watersheds to changing climates, considerations will be drawn on the most resilient setup.

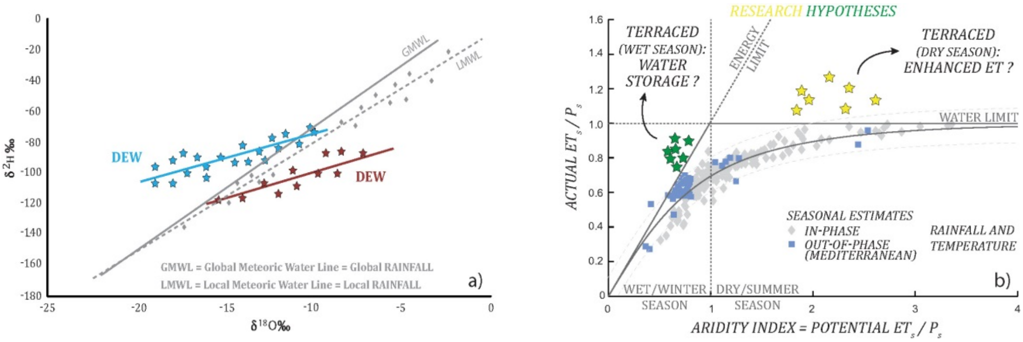

Figure 2. a) A characteristic isotopic signature (blue and red stars and solid lines; hypothesized after Kaseke et al. (2017)) enables distinguishing dew from other water sources (and from the global and meteoric water lines, respectively displayed with solid and dotted grey lines). Isotopic composition of water samples collected from dry-stone walls and nearby agricultural fields might provide information on the fraction of soil moisture supplied by dew deposition in semi-arid regions. b) Hypothesized distinct signatures (green and yellow stars) of broadly terraced watersheds in the Budyko space, compared to standard signatures of catchments with in-phase (grey diamonds) and out-of-phase (blue squares) rainfall and temperature (from Gentine *et al*. (2012)). Markers represents seasonal estimates. If significant amounts of water are stored in terraces during the wet season, watersheds might plot above (or very near) the energy limit. In fact, P – Q = AET + ΔS in this case, which might be larger than PET (P is precipitation, Q is streamflow, AET is actual evapotranspiration, ΔS is storage variation and PET is potential evapotranspiration). Similarly, terraced watersheds might plot above the water limit during the dry season, when enhanced evapotranspiration is enabled by water amounts in excess of seasonal precipitation, which have been stored in terraces during the wet season.

Acknowledgments

The author would like to thank the Center for Mediterranean Integration, CMI Water Hub, the Swedish Institute Alexandria and the Mediterranean Youth for Water Network for having first believed in this project by awarding it as winner of the Second Mediterranean Water Heroes Contest on Nature-based Solutions for a Water Secure Mediterranean (2018).

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