How fragile is it? A GIS-based multicriteria assessment to define management priorities for a Mediterranean terraced system (Tuscany, Italy)

RIZZO Davide [(1) (*)]

(1) UMR LISAH, IRD, Montpellier, France
(*) davide.rizzo@ird.fr

Keywords: Agro-hydrological system, Dry-stone walls, Soil and water management, Olive groves, Landscape agronomy

Introduction

Terraced systems shape the surface water and soil management of many agricultural areas around the Mediterranean coasts (Pinto-Correia and Vos 2004). Terraces, especially dry-stone terraces are probably the best-known example of the various agro-hydrological infrastructures that have been developed all over the world through centuries of agricultural activities. In particular, terraces and the like are anthropic modifications that have a permanent impact on the geomorphological stability due to the intense remodelling of steep slopes (Tarolli et al. 2014). By design, agro-hydrological infrastructures require both continuous anthropic action to maintain each component, and coordination between multiple actors to maintain the functioning of the overall system (Asins Velis 2007).

Due to their poor machinability, many terraced systems have been partially abandoned or completely neglected in recent decades. However, portions of these systems located in peri-urban areas have the potential to transition to neo-rurality. There, newcomers purchase houses and land for settlement purposes, and then resume farming as a part-time or hobby activity, albeit with sporadic or incorrect management practices of the agro-hydrological infrastructures (Van Eetvelde and Antrop 2004; Gennai-Schott et al. 2020). The mix of full-time, part-time, and hobby farmers underpins the evolution of the system management. To provide valuable support to these different land managers and develop new management strategies, the key challenge is to capitalize on prior knowledge about the individual agro-hydrological infrastructures and their place within the overall system (Tarolli et al. 2019).

Several studies and research projects have addressed the management of terraced system, covering various geographic locations and disciplinary or integrative approaches. However, the literature points out two needs yet to be addressed. On the one hand, the ***co-design*** of management, to involve heterogeneous land managers acting at different spatial levels with different purposes. On the other hand, the ***re-design*** of strategies and practices for agro-hydrological infrastructure management with a system approach. This paper discusses some lessons learned from a co-designed method aimed at supporting different actors and stakeholders in prioritising management practices of a terraced system located in the northern Mediterranean (Rizzo et al. 2022).

Description of the case study

The case study is located on the south-western hillside of Monte Pisano (43° 44' N - 10° 32' E, Tuscany, Italy). It was delimited on the administrative boundaries of the three municipalities participating in a series of research projects spanning approximately two decades (Rizzo and Gennai-Schott 2020). The area covers 62 km² and comprises 1,930,000 linear meters of terrace risers on 1,813 hectares of total agricultural surface, with an average density of 1050 m/ha, locally reaching 2,000 m/ha. Most of these risers are made of dry-stone walls. The complexity of the local agro-

hydrological infrastructures and system has been addressed by multiple studies aimed at supporting the local and regional policy and decision-makers in defining management priorities to ensure the proper functioning and stability of the agro-hydrological system.

Terraced system *fragility* was adopted as a concept to link the setting of management priorities and the re-design of management practices from a system perspective. Fragility is a concept used by land managers and policy-makers to express the uncertainties about land management. However, this concept remains vague to be operationalized. In this vein, fragility was defined as the inverse of land suitability and, therefore, assessed as the distance introduced by anthropic modifications from natural constraints, such as slope: the greater the distance, the greater the fragility.

Operationally, fragility was assessed through a GIS-based multicriteria decision-making method, based on two main criteria: structural fragility, related to natural and permanent anthropogenic constraints, and overall fragility, which included agricultural practices. Seven attributes were selected and processed, then aggregated to subdivide the study area into a set of ranked alternatives to address the initial decision problem. Finally, field validation with a Kappa analysis provided stakeholders with measures of the validity of the fragility assessment. The overall assessment was developed within the framework of landscape agronomy to relate farming practices, natural resource management and land patterns (Tarolli et al. 2019).

Lessons learned for a system approach

Four main lessons on the co-design of the assessment method and the re-design of management strategies and practices from a system perspective can be drawn from the case study. The lessons relate to the method co-design process, such as the importance of evaluating the validity of the method (1) and avoiding the "black-box" effect for the uses (2), as well as some challenges, such as the need to improve the communication of validity (3) and to improve the integration of local needs (4).

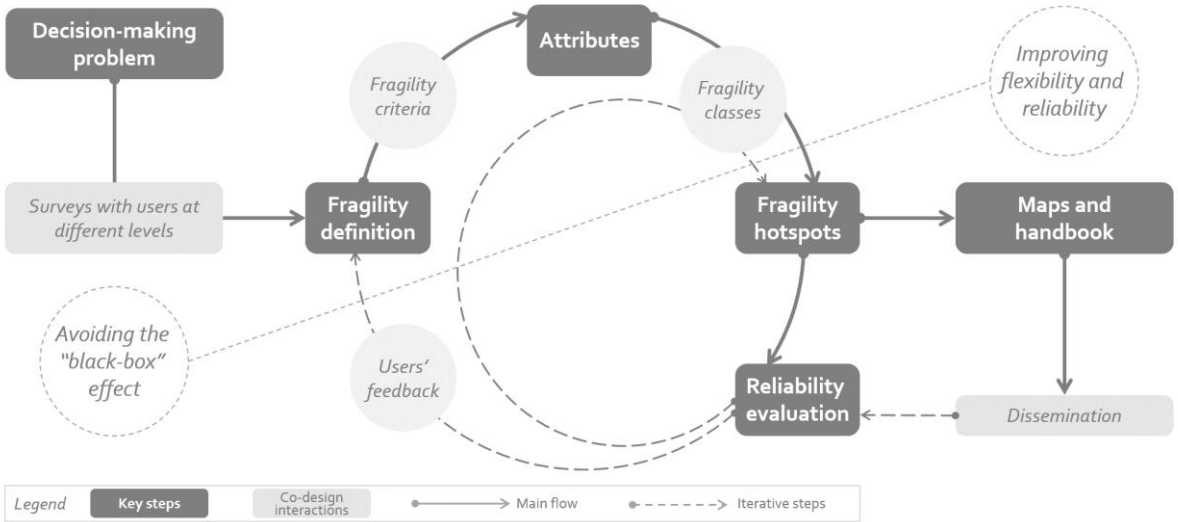

Figure 1. Diagram of the method co-design and evaluation for the fragility assessment: key steps and co-design interactions.

1. **It is necessary to evaluate the validity of the method**. Researchers in geographical sciences emphasise the need to associate validity metrics with the maps delivered to the decision-makers. In the case study, there was a further need to evaluate the validity of the fragility assessment itself. The notion of fragility was it was adopted because it was already used by land managers and local policy-makers. To operationalise it, it was important to achieve a

shared definition and associate it to measurable criteria and attributes, and then classify it so that it could be used to design management strategies (Figure 1). This process allowed to define and prioritise the management issues of the terraced system as a whole, such as the lack of quantitative information about the various agro-hydrological infrastructures that compose it and of their spatial structure. Furthermore, the choice of a spatially explicit multicriteria decision analysis provided the required flexibility and modularity of choices throughout the method co-design process to integrate the perspectives of different actors.

2. **Co-designing avoids the "black box" effect** for land managers and other local decision-makers involved in the process. The involvement of local decision-makers from the very beginning, i.e. from the definition of the decision-making problem, was intended to promote the shared definition and mutual understanding of the assessment choices. Moreover, this process improved the relevance of the results.

3. **Improving the communication of method validity** should complement the co-design process. Indeed, the method co-design process implies several simplifications or approximations of the description and formalisation of the agro-hydrological infrastructures and system to cope with the lack of specific data or to compromise the diverging perspectives of local actors. Hence, decision-makers should be made aware of the validity limits of the method and results for their decision-making process. For instance, this concerns the spatial and temporal scales at which the results are relevant, as well as their possible aggregation to address different levels of analysis. Indeed, validity is multifaceted and so are the relevant metrics for multicriteria models (Qureshi et al. 1999). These metrics include precision, which needs to be calibrated upon the expectations of different users, accuracy, for which spatial and temporal references could not be available, and reliability, which could be evaluated by repeating the assessment. Unfortunately, the multiplicity of the available metrics can be confusing.

4. **Improving the integration of local needs**. In the case study, the decision-makers expressed the need for fragility maps and a handbook to identify and disseminate management solutions. In this sense, the method co-design process supported the re-design of management strategies and practices from a system perspective. The local government adopted the results to improve the coordination for the terraced system management also because of the involvement of the local department of Civil Protection in the overall assessment process. The expected results were completed by a number of co-products of the method targeted to other stakeholders, such as a book on the history of the local terraced landscape, the design of a hiking trail to promote visits to key agro-hydrological infrastructures, and an economic evaluation of the various management practices (Galli et al. 2008; Gennai-Schott et al. 2020).

Conclusion

"How fragile is it?" was the question posed by the local land manager of the terraced system chosen as a case study for this work. This question involved multiple issues: the definition of fragility, its mapping and the identification of possible solutions. Beyond the specific results, the case study was framed within the broader literature about terraced systems to discuss how it operationalised a system approach to the description and management of agro-hydrological infrastructures. The four lessons learned on the co-design of the assessment method and the re-design of management priorities highlight some perspectives for future research. In particular, the proposed GIS-based multicriteria assessment and the procedure for evaluating its validity could be applied to other agro-hydrological systems and other Mediterranean agricultural systems where soil and water management needs to be integrated at the watershed or landscape level.

Acknowledgements

The author warmly thanks Fabio Casella (Comune di Calci), Mariassunta Galli, Enrico Bonari and Tiziana Sabbatini (Scuola Superiore Sant'Anna, Pisa) for their help throughout the project; Alberto Antinori (GeoInformatiX) for the high-quality DEM; Marta Debolini (Scuola Superiore Sant'Anna) for participating in the field survey. The author acknowledges also the contribution of the administrative personnel of the municipalities of Calci, Buti and Vicopisano and the Province of Pisa, as well as the Cooperativa Agrituristica Lungomonte and the Consorzio Toscano Forestale for their support and involvement in the data collection and the continuous feedback during the assessment process.

References

Asins Velis S (2007) Los aterrazamientos mediterráneos. Paradigma ambiental-agro-cultural. Cuad Sostenibilidad Patrim Nat 81–91

Galli M, Rizzo D, Casella F (eds) (2008) Il paesaggio terrazzato del Monte Pisano tra permanenza e mutamenti. ETS, Pisa (Italy)

Gennai-Schott S, Sabbatini T, Rizzo D, Marraccini E (2020) Who Remains When Professional Farmers Give up? Some Insights on Hobby Farming in an Olive Groves-Oriented Terraced Mediterranean Area. Land 9:168. https://doi.org/10.3390/land9050168

Pinto-Correia T, Vos W (2004) Multifunctionality in Mediterranean landscapes-past and future. In: Jongman RHG (ed) The new dimensions of the European landscape. Springer, Wageningen, pp 135–164

Qureshi ME, Harrison SR, Wegener MK (1999) Validation of multicriteria analysis models. Agric Syst 62:105–116. https://doi.org/10.1016/S0308-521X(99)00059-1

Rizzo D, Gennai-Schott SC (2020) Contributo alla tutela del paesaggio terrazzato toscano. Bilancio di vent'anni di esperienze di studio della fragilità delle sistemazioni idraulico-agrarie del Monte Pisano

Rizzo D, Sabbatini T, Bonari E (2022) A Method to Assess the Fragility of a Terraced System as an Example of Landscape Agronomic Analysis. In: Rizzo D, Marraccini E, Lardon S (eds) Landscape Agronomy: Advances and Challenges of a Territorial Approach to Agricultural Issues, 1st edn. Springer International Publishing, Cham, Switzerland, pp 113–159

Tarolli P, Preti F, Romano N (2014) Terraced landscapes: from an old best practice to a potential hazard for soil degradation due to land abandonment. Anthropocene. https://doi.org/10.1016/j.ancene.2014.03.002

Tarolli P, Rizzo D, Brancucci G (2019) Terraced Landscapes: Land Abandonment, Soil Degradation, and Suitable Management. In: Varotto M, Bonardi L, Tarolli P (eds) World Terraced Landscapes: History, Environment, Quality of Life. Springer International Publishing, Cham, pp 195–210

Van Eetvelde V, Antrop M (2004) Analyzing structural and functional changes of traditional landscapes—two examples from Southern France. Landsc Urban Plan 67:79–95. https://doi.org/10.1016/S0169-2046(03)00030-6