International Cartographic Association
Association Cartographique Internationale

Challenges of deep learning recognition of cultivated terraces and their mapping: The case of Slovenia

Rok Ciglič [a,*], Luka Čehovin Zajc [b], Anže Glušič [c], Lenart Štaut [a]

[a] *Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute – rok.ciglic@zrc-sazu.si, lenart.staut@zrc-sazu.si*

[b] *University of Ljubljana, Faculty for computer and information Science – luka.cehovin@fri.uni-lj.si*

[c] *anze.glusic@gmail.com*

* Corresponding author

Keywords: cultivated terraces, mapping, register of terraces, deep learning, lidar, Slovenia

Abstract:

Maps represent the real world, including many artificial phenomena. Some of these are easy to recognise (e.g. houses), but some are less obvious. Cultivated terraces are somehow in between. In various parts of the world, they are carved into slopes by humans to gain agricultural land, reduce soil erosion, increase soil moisture etc. Terraces usually consist of a flat or slightly sloped surface of varying width that is cultivated and a terrace bank of varying height. They are important in some areas where entire stretches of land are designated as terraced landscapes, while elsewhere they can only be recognized upon detailed inspection (Kladnik et al. 2017).

There is a need to map terraces in order to manage and protect them, as they play an important role in food production. To raise their awareness, the Honghe Declaration was adopted worldwide in 2010. Previous studies have shown the diversity of cultivated terraces, but they have not fully implemented procedures for their automatic detection and accurate mapping, especially in vegetated areas. Some terraces are easy to recognise, but others are less visible due to overgrowth. The usefulness of lidar data visualisation and analysis has been highlighted in several recent studies (e.g. Ferrarese et al. 2019; Alberti 2020). Lidar allows a detailed study on landscape topography even below the tree canopy. This is an important capability for mapping and research in vegetation-rich countries, such as Slovenia.

There have been some attempts to map the locations of terraces in order to create a map or register of terraces. In Slovenia, terraced landscapes were first documented at the country level by visual examination of orthophotos, topographic maps and fieldwork by Kladnik et al. (2017). At the time of that study, lidar data was not yet available and the interpretation of optical remote sensing imagery failed to detect overgrown cultivated terraces (Figure 1). As a result, the register of terraces in Slovenia was incomplete. Recently, Lu et al. (2023) and Zhao et al. (2021) introduced deep learning methods to detect terraces in China using satellite imagery and optimised their results with the help of predefined masking (e.g. to eliminate flat areas with a digital elevation model (DEM) or non-agricultural areas with a land use map). Ciglič et al. (2024) recently tested the use of deep learning methods (U-Net) for the detection of terraces in Slovenia based solely on lidar data. The existing dataset of terraces from Kladnik et al. (2017) was used as a learning set. Although the learning set was noisy due to the incomplete register of terraces, the modelling was possible, although not very accurate in many cases (Figure 2). The analysis of the agreement between the Kladnik's terrace register and the terraces recognised by deep learning showed that the overall accuracy of the model was 85%, but the kappa index was only 0.22. The success rate varied across the country. This study was the first attempt at deep learning terrace detection based solely on high-resolution DEM, highlighting examples of false terrace recognition that may be related to natural or other artificial terrace-like features.

Now there are new attempts in progress to provide a complete map of terraces in Slovenia. In 2025, a new research project was launched that aims to: a) provide updated training sets and deep learning algorithms (based on U-Net) that can objectively recognize cultivated terraces, and b) analyse the characteristics of Slovenian cultivated terraces in space and time based on a new cultivated terrace database. Within the project, training and validation samples will be manually mapped based on lidar visualisation techniques (e.g. hillshade), which was not possible in previous research attempts (e.g. Kladnik et al. 2017). Therefore, much higher recognition success rates are expected compared to previous attempts (Ciglič et al. 2024) based on Kladnik's terrace register, which contained also incorrect training samples of terraces. The improved database of cultivated terraces will fill the gap by adding missing terraces and creating an updated register and map of terraces in Slovenia.

In this presentation we would like to present an existing manually defined terraces register (Kladnik et al. 2017) and first attempts of deep learning detection (Ciglič et al. 2024) and point out their weaknesses as well as present a plan for the detection of terraces and the creation of a new register (a presentation of the ongoing project workflow).

In a hilly country like Slovenia, which has under a tenth of flat terrain, terraces are particularly important. The country boasts high level of landscape diversity as different European landscape regions meet here (the Alps, the Pannonian

Basin, the Mediterranean and the Dinaric Alps). Therefore, the knowledge about Slovenian terraces can be transferred to other European regions and the newly developed method for recognising terraced landscapes would also be useful in other countries with lidar data. With the presentation of our work and the proposed research, we would like to discuss appropriate training and validation sets selection, and debate about presentation of the final register of terraces in the form of maps or web atlases. We will also present usefulness of the results, especially related to the Slovenian rural policy, which recognises terraces as an important element for preventing erosion and preserving the cultural landscape.

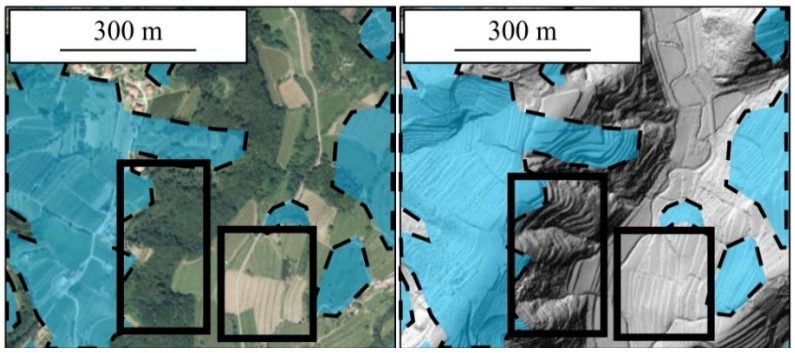

Figure 1. Example of mapped cultivated terraces based on orthophotos (left) compared to a modern 1m shaded relief (right). Some cultivated terraces that are visible on the shaded relief and have been overgrown with vegetation were not recorded during photointerpretations in the Kladnik et al. (2017) research. Basemaps: Surveying and Mapping Authority of the Republic of Slovenia; Slovenian Environment Agency.

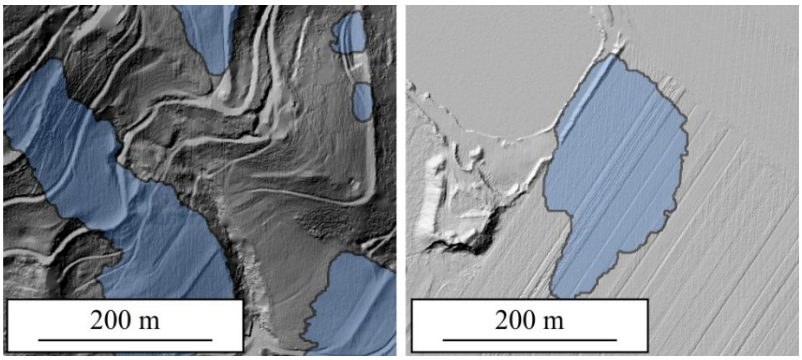

Figure 2. False recognition of cultivated terraces by Ciglič et al. (2024) resulted in overestimation of terraced areas. Example of roads (left) and fields in the plain (right) recognized as terraced areas. Basemaps: Slovenian Environment Agency.

Acknowledgements

The authors acknowledge financial support by the Slovenian Research and Innovation Agency project 'The Life and Death of Cultivated Terraces: Computer-Based Recognition and Spatial Analysis of Terraces' (L6-60160) and young researcher program (MR-56874), and the Slovenian Research and Innovation Agency research core funding programs 'Geography of Slovenia' (P6-0101) and 'Computer Vision' (P2-0214).

References

Alberti, A. P. 2020. Cartography of the terraces (socalcos) in Galicia (northwest Spain): An original approach. In: *The Journal of Terraced Landscapes* 1-1, pp. 9–33.

Ciglič, R., Glušič, A., Štaut, L., Čehovin Zajc, L. 2024. Towards the deep learning recognition of cultivated terraces based on Lidar data: The case of Slovenia. In: *Moravian Geographical Reports* 32-1, pp. 66–78.

Ferrarese, F., Pappalardo, S. E., Cosner, A., Brugnaro, S., Alum, K., Dal Pozzo, A., De Marchi, M. 2019. Mapping agricultural terraces in Italy. Methodologies applied in the MAPTER Project. In: *World Terraced Landscapes: History, Environment, Quality of Life. Environmental History 9*, pp. 179–194.

Kladnik, D., Perko, D., Ciglič, R., Geršič, M. (eds) 2017. *Terraced Landscapes*. Ljubljana, 148 p.

Lu, Y., Li, X., Xin, L., Song, H., Wang, X. 2023. Mapping the terraces on the Loess Plateau based on a deep learning-based model at 1.89 m resolution. In: *Scientific Data 10-1*, pp. 1–15.

Zhao, F., Xiong, L., Wang, C., Wang, H., Wei, H., Tang, G. 2021. Terraces mapping by using deep learning approach from remote sensing images and digital elevation models. In: *Transactions in GIS* 25-5, pp. 2438–2454.