[1]Division of Geography and Tourism, Department of Earth and Environmental Sciences, KU Leuven, Belgium
[2]Archaeology, Environmental Changes & Geo-Chemistry research group (AMGC), Vrije Universiteit Brussel, Belgium

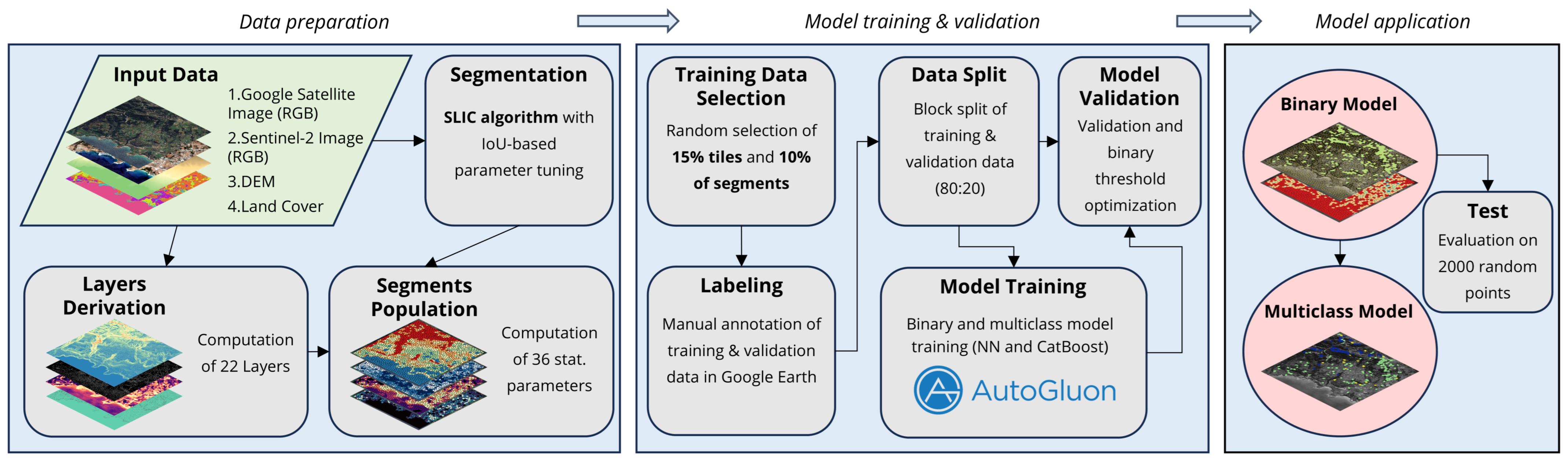
Automatic mapping of terrace systems at large scales: a case study of Cyprus

Andrei Kedich[1,2], Ralf Vandam[2], Soetkin Vervust[2], Yannick Devos[2], and Matthias Vanmaercke[1]

Introduction

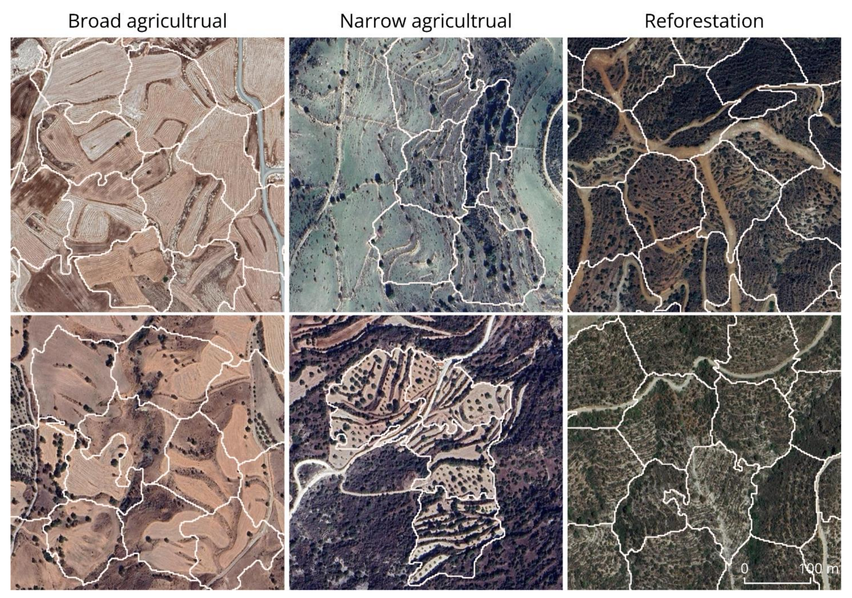
- **Agricultural terraces** are widespread landforms that **support cultivation** in mountainous areas while preserving slope stability and **reducing erosion risks**. Despite their practical and historical value, many are **deteriorating** due to abandonment driven by socio-economic factors.
- **The geomorphic role of terraces** is complex: they modify slope morphology, reduce runoff, and **limit erosion**, but can also **trigger gullying or landslides**, especially when poorly maintained. Their influence on sediment dynamics is significant but still not fully understood.
- Terrace detection often relies on high-resolution data (e.g., UAV, LiDAR) and is typically performed at local to regional scales. This research develops a new framework that uses **freely available data** in combination with **object-based image analysis (OBIA) and machine learning (ML)** to detect and classify terraces at larger scales. Cyprus is chosen as the test region due to its rugged terrain, diverse terrace types, and ongoing land-use changes.

Methodology

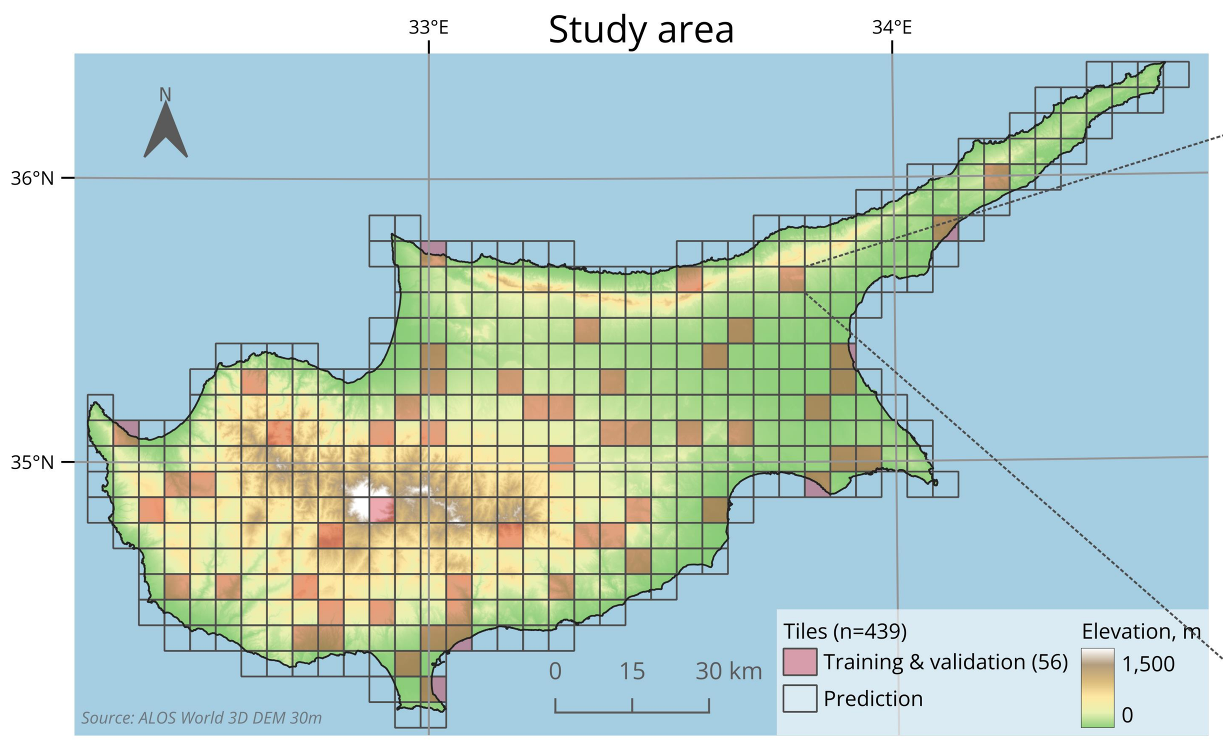


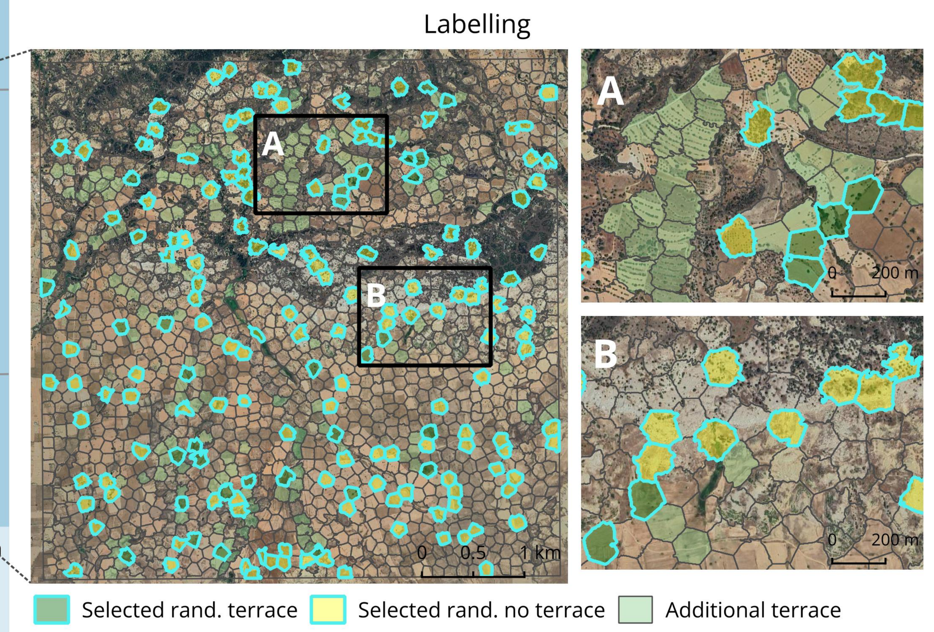
Detection and classification workflow

- **Input data**: Google satellite imagery (2.11 m/pix), Sentinel-2 imagery (July 2021, 10 m/pix), ALOS DEM (25 m/pix), ESA WorldCover 2021 (10 m/pix)
- **Derived layers** included 7 gray-level co-occurrence matrix (GLCM) textures, Canny edges, slope and slope-related filters (slope direction, profile, and plan curvature).
- **Segmentation** was performed using Simple Linear Iterative Clustering (**SLIC**), generating superpixels that preserve regularity and are robust to spectral variability. Segments were populated with statistics from the derived layers.
- **Binary and multiclass models** (AutoGluon) are trained and validated using block splitting on 9,567 manually labelled segments, followed by additional point-based testing.



Terrace classification types





Study area and training data collection

Results

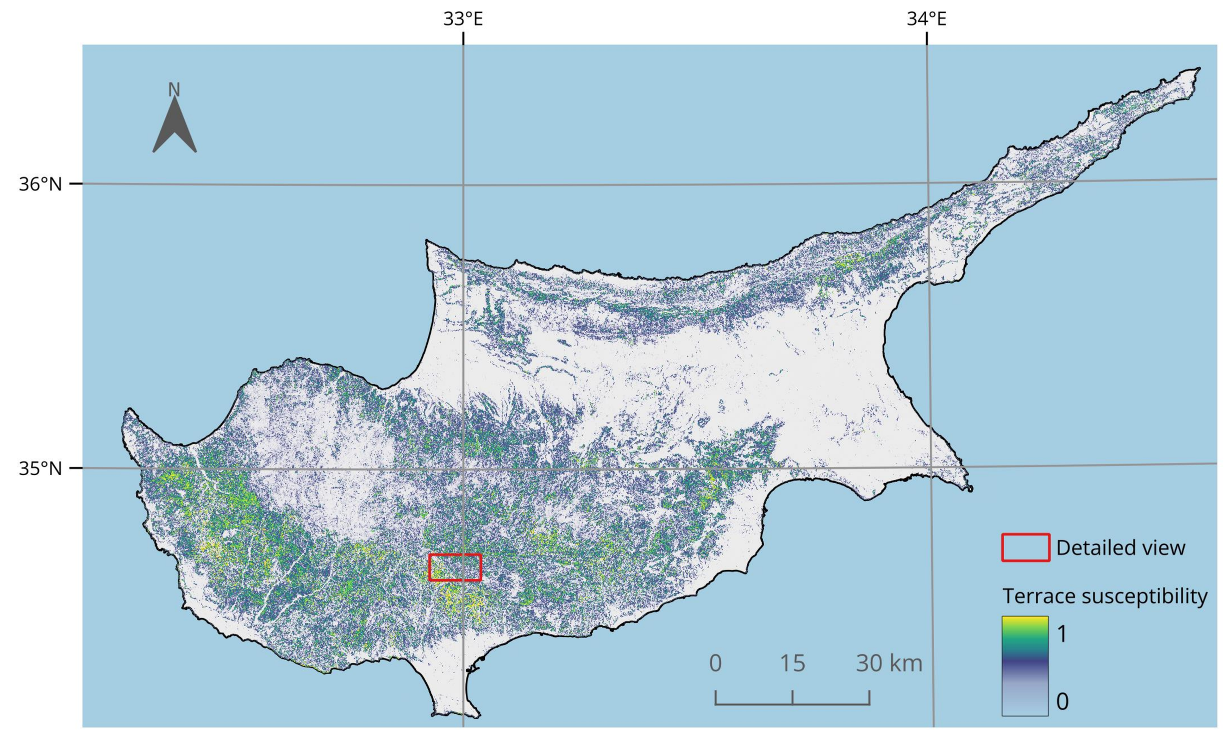
- The total area predicted as terraced using the balanced threshold is **688 km²**, representing **7.5% of Cyprus**. Around **47% are broad** agricultural terraces, **41% narrow** agricultural terraces, and 12% terraces for reforestation.
- For **binary terrace detection**, the most influential predictors were **green** reflectance, **elevation range**, and **land cover**. In the **multiclass classification**, **texture features** played a dominant role, with a notable lead for homogeneity, standard deviation, and contrast (GLCM features).
- **Point-based validation** of the whole framework (segmentation + classification) confirmed strong model performance, yielding an overall **accuracy of 0.86**, **balanced accuracy of 0.70**, **F1-score of 0.49**, and **MCC of 0.42**.

Binary classification metrics

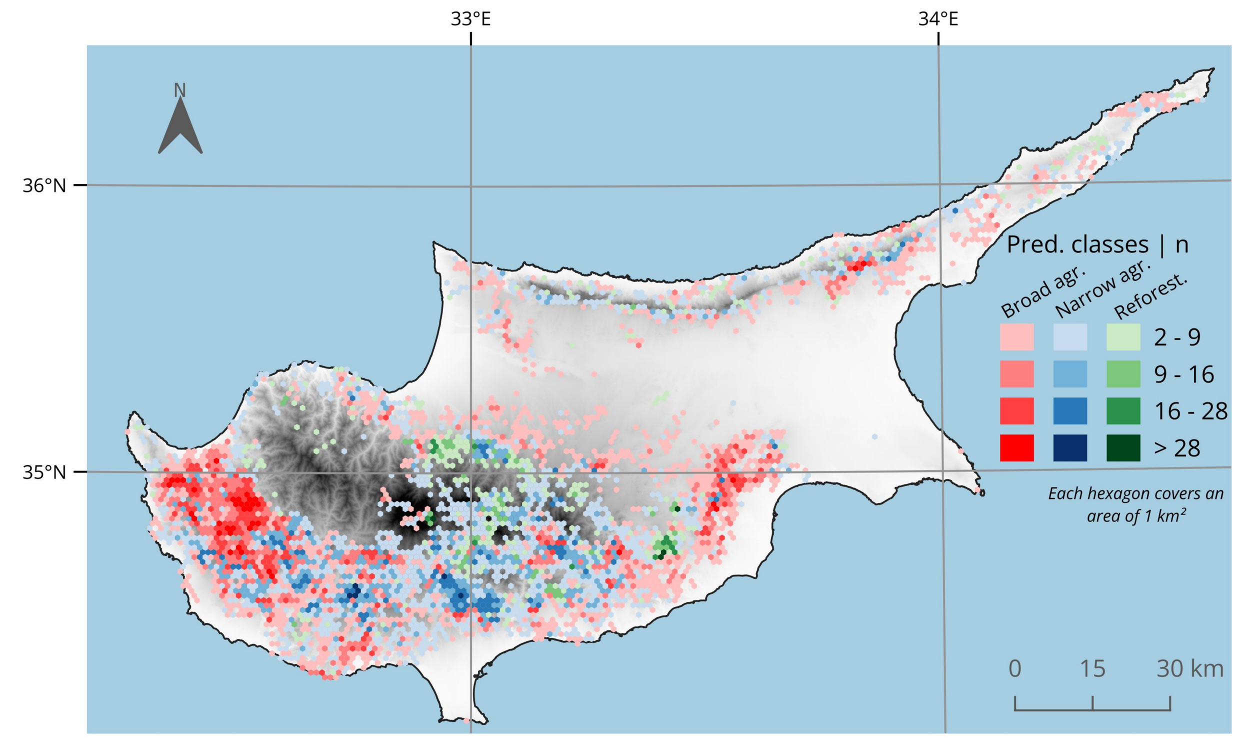
Accuracy	*Balanced accuracy*	*F1 (=Precision & Recall)*	*MCC*	*ROC AUC*
0.88	0.69	0.44	0.37	0.86

Multiclass classification metrics

Class	*Accuracy*	*Precision*	*Recall*	*F1-score*	
Broad agr.	0.94	0.62	0.94	0.75	
Narrow agr.	0.56	0.77	0.56	0.65	
Reforest.	0.38	0.58	0.38	0.46	
			Overall statistics	*MCC*	0.49
				Macro F1	0.62
				Weighted F1	0.66



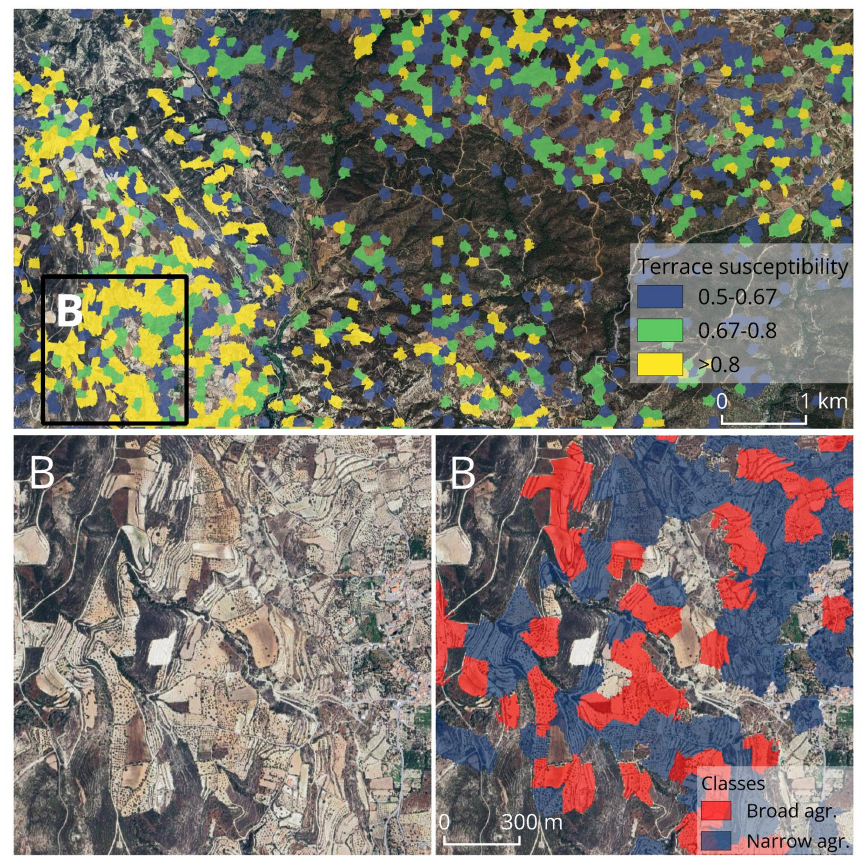
Predicted terrace susceptibility



Frequency of predicted terrace classes

Discussion

- Both classifications demonstrated an **acceptable level of accuracy** for large-scale terrace mapping, accounting for the sole reliance on open-access data. Threshold optimization enabled **close-to-reality estimates of terrace coverage** across the island while also helping to highlight terracing hotspots, though some misclassifications remain.
- **Broad and narrow** agricultural terraces were **accurately distinguished**, whereas **reforestation** terraces were more frequently **misclassified**, likely due to their morphological position on steep hillslopes, similar to that of narrow terraces, and more complex vegetation patterns, with parts of terraces covered by tree canopy.



Detailed view; susceptibility & predictions

Conclusion

- This study demonstrates the **potential for large-scale detection and classification of terraces** using only freely available satellite and elevation data through a hierarchical OBIA and machine learning approach.
- Such large-scale terrace mapping is highly **promising for erosion modeling**, as terraces are a critical component of the P-factor in RUSLE, yet large-scale assessments of it remain limited and rudimentary. Additionally, it supports **geoarchaeological research**, since terraces can provide valuable insights into historical land use and history of human occupation.

Abstract

Contact information
andrei.kedich@kuleuven.be
@andrei_kedich