GEO MORPHOMETRY 2025
PERUGIA ITALY JUNE 9-13

Soil Erosion And Intensive Agriculture (Lessini Veronesi, NE Italy): Multi-Temporal Modelling On DEMs From Photogrammetry And Lidar

Barbara Rigon[1], Sandro Rossato[2], Giacomo Vinci[1], Stefano Castelli[1], Paolo Mozzi[1]
[1] Department of Geosciences, University of Padua
Via Gradenigo 6 – 35131 - Padova, Italy
[2]Institute of Geosciences and Georesources, National Research Council of Italy
Corso Stati Uniti, 4 - 35127 – Padova, Italy

Abstract—**The study evaluates the impact of intensive vine cultivation on soil erosion near Verona, in the Monteforte d'Alpone area, with an innovative technique consisting of the multi-temporal analysis of Digital Elevation Models (DEMs) derived from photogrammetry and LiDAR (Light Detection and Ranging).**

By applying the Revised Universal Soil Loss Equation (RUSLE) model to a 1981 DTM (Digital Terrain Model) generated through photogrammetry of aerial photos and to a LiDAR-derived DTM from 2008, the study analyses changes in soil erosion over time. The mean potential soil erosion rates calculated for the study area are 20.95 (Mg ha^{-1} yr^{-1}) in 1981 and 15.72 (Mg ha^{-1} yr^{-1}) in 2008, which are 20 and 15 times higher, respectively, than the thresholds considered sustainable in a comparable European-scale analysis (Verheijen et al., 2009). The results have been compared with DEMs generated in summer 2024 by drone-based photogrammetry and LiDAR, to evaluate accuracy and verify the correlation between erosion predictions and present field conditions.

The application of RUSLE modelling to estimate soil erosion yielded consistent results across the years 1981, 2008 and 2024, that were corroborated by observations carried out in the field, demonstrating it is possible to generate high-resolution DEMs from aerial photogrammetry, which are suitable for the application of soil erosion models, such as RUSLE.

I. INTRODUCTION

Vineyards are among the agricultural crops causing the highest rates of soil erosion (Pappalardo et al., 2019; Strafellini et al., 2022), a significant environmental issue that reduces biodiversity and increases slope instability (Pimentel et al., 2006). The hills of Monteforte d'Alpone, the production area of Soave DOC wine, provide an ideal setting to study soil erosion using the Revised Universal Soil Loss Equation (RUSLE) model (Renard et al., 1997). Widely adopted by the European Union for land management assessments, this empirical model combines data on topography, soil, precipitation, and land use within a GIS framework, relying on Digital Elevation Models (DEMs) (Pappalardo et al., 2019).

Until recently, the application of RUSLE has been constrained to recent scenarios due to the need for high-resolution DEMs that were poorly available before the advent of LiDAR technology. Nowadays, advancements in photogrammetric techniques allow for the generation of detailed DEMs from historical aerial photos (Natale et al., 2024), that enable multi-temporal analyses of soil erosion.

The aim of this study is to estimate the diachronic soil erosion in the Monteforte d'Alpone area by applying the RUSLE model to two DEMs from different time periods: the first one generated through photogrammetry from 1981 aerial photos, and the second one from 2008, obtained through LiDAR aerial surveys, in order to evaluate changes in potential soil erosion over time.

II. MATERIAL AND METHODS

A. Aerial photos

To assess the evolution of the morphology of the area, aerial photographs freely available on the Geoportal of the Veneto

Region (https://idt2.regione.veneto.it/) were used. All photos were georeferenced in QGIS, in order to evaluate the geomorphological evolution over time and identify areas subject to instability or frequent human interventions, indicators of potentially high soil erosion rates. Five areas of interest (A, B, C, D, E) were identified (Fig. 1). The reference system used is Monte Mario Zone 1 (EPSG: 3003), as it minimizes the distortion of the aerial photos during the georeferencing process. Once identified the five zones, direct observations were conducted in the field to evaluate the actual slope stability conditions.

Fig. 1: areas with probable instabilities identified through aerial photographs in QGIS.

B. *Aerial photogrammetry*

The 1981 DEM of the Monteforte d'Alpone area was created from 11 black-and-white aerial photos taken during the Reven flight (12 April–13 October 1981). Pre-processing involved FIJI/ImageJ software to improve image quality and align the photos for the subsequent photogrammetry in Agisoft MetaShape. Fiducial points ensured precise alignment, with one photo set as reference, oriented to cardinal directions. The BigWarp plugin helped match fiducial points between fixed and moving images, rotating them for accurate overlap. After alignment, the image contrast was adjusted based on the sharpest photo. The enhanced images were imported into Agisoft MetaShape, where masks excluded irrelevant areas, and a sparse points cloud (Fig. 2) was generated and georeferenced by placing markers. Image alignment was optimized using all available parameters, resulting in dense point clouds (Fig. 3).

Processing was done on a standard laptop (Intel Core i5-8265U, 24GB RAM) and took about 1.5 hours, demonstrating MetaShape's efficiency. Finally, the dense point cloud was used to create an orthomosaic and a DTM with a resolution of 1.48 m/pix and a Root Mean Square Error (RMSE) of 0.242 m (Fig. 4).

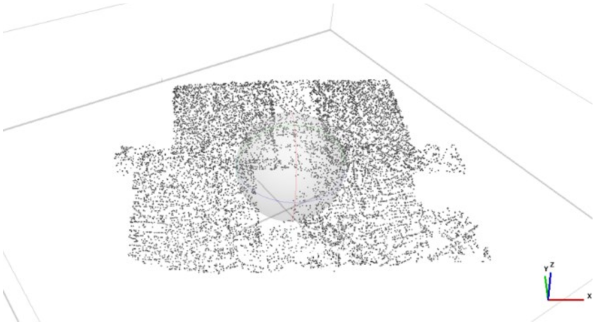

Fig. 2: sparse point cloud obtained from photo alignment in Agisoft MetaShape.

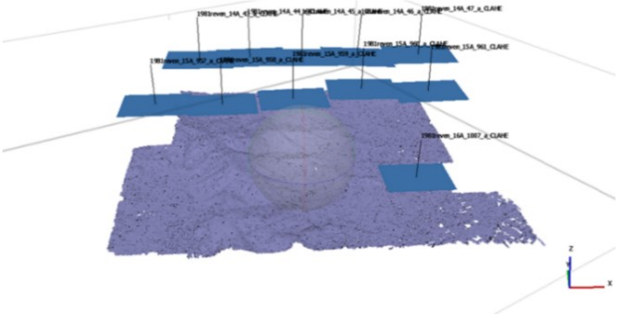

Fig. 3: high quality dense cloud generated from the sparse points cloud in Agisoft MetaShape.

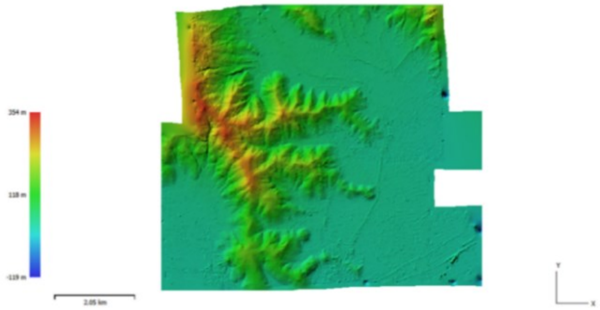

Fig. 4: DTM obtained from 1981 aerial photos through photogrammetry with Agisoft MetaShape.

C. *Drone photogrammetry and LiDAR.*

Drones equipped for photogrammetry and LiDAR surveys were used to generate high-resolution DEMs, offering precise data on current conditions in the study area. These datasets were compared with 1981 and 2008 models to evaluate erosion and other terrain changes and provide images of the landslides occurring in the study area. The surveys were conducted in August 2024.

A drone-based photogrammetric DSM was produced for Zone B, which shows notable evidence of surface erosion. Data collection was carried out with a DJI MAVIC 3 ENTERPRISE drone, featuring a GNSS system with RTK corrections. Images were taken during two flights along perpendicular paths to optimize coverage and reduce vegetation interference. Georeferencing used a "base-rover" system, with an Emlid Reach RS2+ GPS providing RTK corrections via the NTRIP network. The 422 images collected were processed in Agisoft MetaShape, creating a medium-quality dense cloud and a final DSM with 8.47 cm/pix resolution (Fig. 5).

LiDAR surveys were performed in zones B and C. Zone B, with significant surface erosion, and zone C, covered in dense vegetation, were surveyed using the Zenmuse L2 system mounted on a MATRICE 350 RTK drone. The LiDAR system produced DSM with resolution 0.5 m/pixel (Fig. 6). The RMSE has a value of 0.227 m.

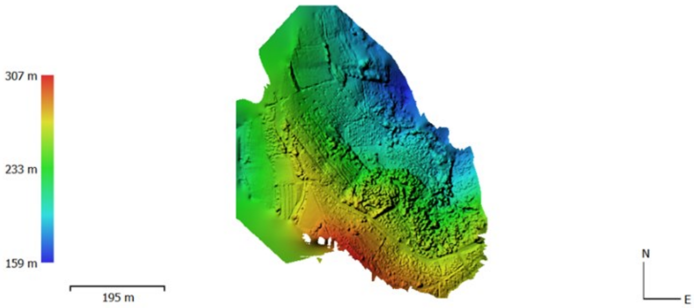

Fig. 5: zone B DSM obtained from drone images through photogrammetry with Agisoft Metashape.

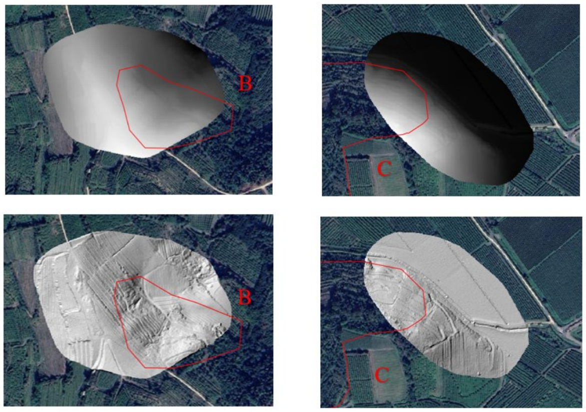

Fig. 6: zones B and C DSM obtained from LiDAR acquisitions. QGIS.

D. RUSLE

The RUSLE model (Renard et al., 1997), widely used in the European Union for land management assessments, was chosen for this study due to its proven effectiveness in similar contexts, such as the Prosecco DOCG region (Pappalardo et al., 2019). RUSLE calculates soil erosion rates (A) by integrating factors like rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), vegetation cover (C), and cultivation practices (P). Due to limited historical data and time constraints, the P factor was excluded from the equation. For each variable, separate raster datasets were generated in QGIS for 1981 and 2008.

Rainfall erosivity (R) was modeled using Panagos et al. (2021) data from the REDES (Rainfall Erosivity Database at European Scale) database. Precipitation data from seven ARPAV (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto) stations were interpolated to create raster layers for 1981 and 2008. The soil erodibility factor (K) was taken from the ESDAC (European Soil Data Centre) 2014 soil erodibility map, based on the 2009 LUCAS (Land Use/Cover Area frame Survey) survey. Slope length and steepness (LS), key morphological factors, were calculated using 1981 and 2008 DEMs processed for hydrological consistency with the Erosion Flow plugin. LS overestimations on structural highs matched findings by Benavidez et al. (2018) and were higher for 1981, due to the lower DEM resolution. Vegetation and land use (C) were derived from CORINE Land Cover data and ARPAV (2017) coefficients. Land cover polygons for 1981 and 2008 were manually digitized in QGIS, based on aerial photographs for 1981 and satellite imagery for 2008 and C values were accordingly assigned. Final soil erosion maps for 1981 and 2008 were generated by combining R, K, LS, and C rasters with the Raster Calculator tool of QGIS, using the 1981 DEM as the resolution reference. This ensured that all input and output rasters had a uniform resolution of 1.48 m/pix.

III. RESULTS AND DISCUSSION

The application of RUSLE in the Monteforte d'Alpone area for 1981 showed an average potential soil erosion rate of 20.95 (Mg ha^{-1} yr^{-1}), significantly higher than the European sustainable threshold of 1 (Mg ha^{-1} yr^{-1}) based on the expected soil formation rate of 1.4 (Mg ha^{-1} yr^{-1}) (Verheijen et al., 2009). Erosion was most severe on slopes and incisions due to surface runoff, while lower values were observed on flat areas (Fig. 7). Vineyards and arable lands, having the highest C values, contributed the most to erosion, while areas with dense vegetation, which have the lowest C values, had reduced rates.

By 2008, the average erosion rate decreased to 15.72 (Mg ha^{-1} yr^{-1}), showing modest improvement, but still exceeding the expected soil formation rate (Fig. 8). Erosion patterns remained similar, with high rates along steep slopes, indicating LS as the determining factor for the erosion rate. Land use remained a key factor, with vineyards and arable lands showing the highest erosion and vegetated areas offering a stabilizing effect.

A comparison between 1981 and 2008 highlighted the improved accuracy of the 2008 DTM, reducing overestimation of the LS factor on steep slopes. Changes in vegetation also affected erosion patterns: abandoned vineyards replaced by chestnut forests in Zone C reduced erosion, while vegetation loss in Zone D increased instability. Remedial measures such as afforestation and terracing stabilized soils in erosion-prone areas.

Results were confirmed through field observation and visual analysis of 2024 LiDAR and photogrammetric DEMs from drone on the small test areas. These data were compared with previous studies in the region (Pappalardo et al., 2019) and the 2016 ESDAC European erosion map, confirming its usefulness in assessing and predicting soil erosion.

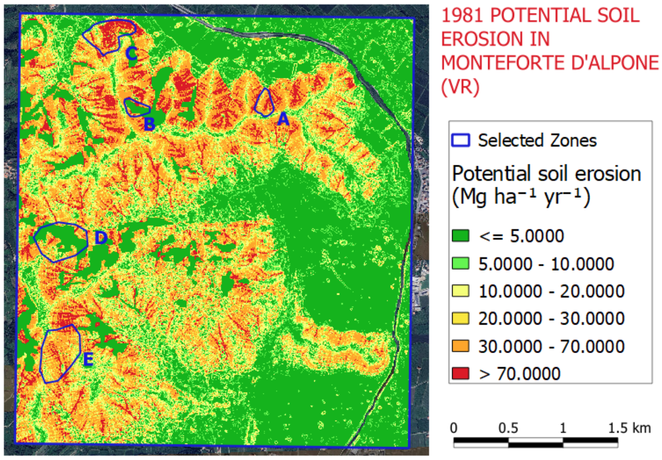

Fig. 7: Soil erosion map of 1981 near Monteforte d’Alpone, produced using the application of RUSLE in QGIS**.**

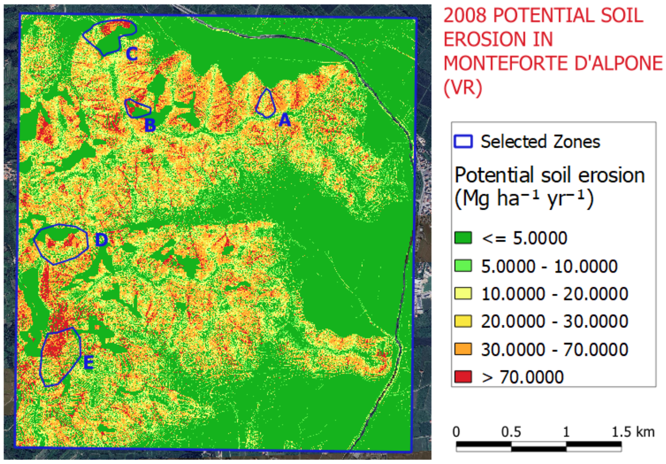

Fig. 8: Soil erosion map of 2008 near Monteforte d’Alpone, produced using the application of RUSLE in QGIS**.**

IV. CONCLUSIONS

In conclusion, it is possible to reconstruct high-resolution digital elevation models from historical aerial photographs using photogrammetry and to apply soil erosion models to analyze past and present land conditions. Using the RUSLE model, soil erosion was estimated for a 1981 DEM derived from photogrammetry and a 2008 DEM generated from LiDAR data, yielding results consistent with current field observations and land management practices.

The analysis of soil erosion changes between 1981 and 2008 correlates with land-use changes and slope modifications. Findings are consistent with similar studies, such as Pappalardo et al.'s 2019 erosion estimates in the Prosecco DOCG area and ESDAC’s 2016 European soil erosion map.

There were difficulties in acquiring historical rainfall and soil data, particularly for 1981, which required making approximations to address the gaps.

The study emphasizes the critical role of DEM accuracy and resolution in determining soil erosion rates. Applying RUSLE to multi-temporal DEMs allows for comprehensive soil erosion analyses over time. Future improvements include refining the K factor with detailed soil data and incorporating the P factor through historical conservation and cultivation data to enhance result precision and support sustainable land management planning.

REFERENCES

[1] Pappalardo, S. E., Gislimberti, L., Ferrarese, F., De Marchi, M., & Mozzi, P., 2019. Estimation of potential soil erosion in the Prosecco DOCG area (NE Italy), toward a soil footprint of bottled sparkling wine production in different land-management scenarios. *PLOS ONE, 14*(2), e0210922. https://doi.org/10.1371/journal.pone.0210922

[2] Straffelini, E., Pijl, A., Otto, S., Marchesini, E., Pitacco, A., & Tarolli, P., 2022. A high-resolution physical modelling approach to assess runoff and soil erosion in vineyards under different soil managements. *Soil & Tillage Research, 222*, 105418. https://doi.org/10.1016/j.still.2022.105418

[3] Pimentel, D., 2006. Soil erosion: a food and environmental threat. *Environment, Development and Sustainability, 8*(1), 119–137. https://doi.org/10.1007/s10668-005-1262-8

[4] Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C., 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). *USDA Agricultural Research Service*, Agriculture Handbook No. 703.

[5] Natale, J., Vitale, S., Repola, L., Monti, L., & Isaia, R., 2024. Geomorphic analysis of digital elevation model generated from vintage aerial photographs: A glance at the pre-urbanization morphology of the active Campi Flegrei caldera. *Geomorphology, 460*, 109267. https://doi.org/10.1016/j.geomorph.2024.109267

[6] Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A., et al., 2021. Reconstruction of past rainfall erosivity and trend detection based on the REDES database and reanalysis rainfall. *Journal of Hydrology, 603*, 126984. https://doi.org/10.1016/j.jhydrol.2020.126984

[7] ARPAV, 2017. Valutazione del rischio di erosione per la Regione Veneto - Aggiornamento 2017. Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto. https://www.arpa.veneto.it

[8] Benavidez, R., Jackson, B., Maxwell, D., & Norton, K., 2018. A review of the (Revised) Universal Soil Loss Equation ((R)USLE): with a view to increasing its global applicability and improving soil loss estimates. *Hydrology and Earth System Sciences, 22*(11), 6059–6086. https://doi.org/10.5194/hess-22-6059-2018

[9] Verheijen, F. G. A., Jones, R. J. A., Rickson, R. J., & Smith, C. J., 2009. Tolerable versus actual soil erosion rates in Europe. *Earth-Science Reviews, 94*(1–4), 23–38. https://doi.org/10.1016/j.earscirev.2009.02.003