Erosion dynamic modelling in semi-humid badlands areas: the role of land use change

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1. Introduction and state of the art

The land use change resulted in the loss of 35.9 Pg of soil due to erosion (Borrelli et al., 2017). Investigating the relation between land use and erosion is crucial as the latter drives land degradation, which impacts soil fertility and causes off-site problems including eutrophication, flooding and landslides etc (Lal 1998; Vergari 2011). This relation is particularly evident in the sub-humid badlands landscape, particularly in the Mediterranean region, where these high erosion landforms often emerge due to land mis-management practices, connected to deforestation, grazing, burning, cultivation, etc (Amici et al., 2017; Moreno-de las Heras and Gallart, 2018; Martínez-Murillo and Nadal-Romero, 2018; Torri et al., 2018). Research typically focuses on analysing the current erosion rates, often overlooking the role and impact of anthropogenic activities on erosion dynamics over time. Indeed, the badlands areas that have undergone anthropic action evolve over time in a different way than the natural ones, showing a distinct erosion dynamic. Torra et al., 2023 suggests that due to complex erosive dynamics, a model able to consider extensive data, as machine learning susceptibility models, is essential and this is in accord with Gayen et al. (2019), Vanmaercke et al. (2020), Mohammady et al. (2022). However, machine learning models demonstrate accurate predictions when the training and test areas match, but their performance decreases when they differ (Torra et al., 2023). Developing a versatile erosion model for badlands areas that have experienced significant historical changes by humans, capable of generating results beyond its training area, thus leading to achieving a generalized model, continues to be a challenge. The Upper Orcia Valley, located in Southern Tuscany (Central Italy), is a key site for studying the denudation processes and human impact in Mediterranean badland areas; it is highly representative as a sub-humid Mediterranean badlands, and the development of landforms generated by surface runoff occurs rapidly on soft bedrock (Pliocene and Pleistocene clays), uncovered after deforestation practices, grazing or the occurrence of landslides (Vergari et al., 2013; Aucelli et al., 2016; Torri et al., 2018). Average rainfall is around 700 mm, with peaks in November and spring; a dry summer followed by autumn rains intensifies erosion. The anthropic pressures in this area are dated far in time, starting from the deforestation in Roman period. In particular, during the Fascist period, a vigorous reclamation program aimed to level erosive landforms on hillsides, employing dynamite and bulldozers to reduce sediment transport and enhance land profitability for agriculture. The ongoing effects of these remarkable modifications were testified, but still not fully analysed. Moreover, in the last decades, the area has been experiencing farming activity abandonment, leading to general increased vegetation via reforestation and natural recolonization; strong channel adjustments have occurred along the main rivers during the last century (Rinaldi, 2003), indicating reduced sediment supply and a decreased hillslope-channel connectivity (Figure 1).

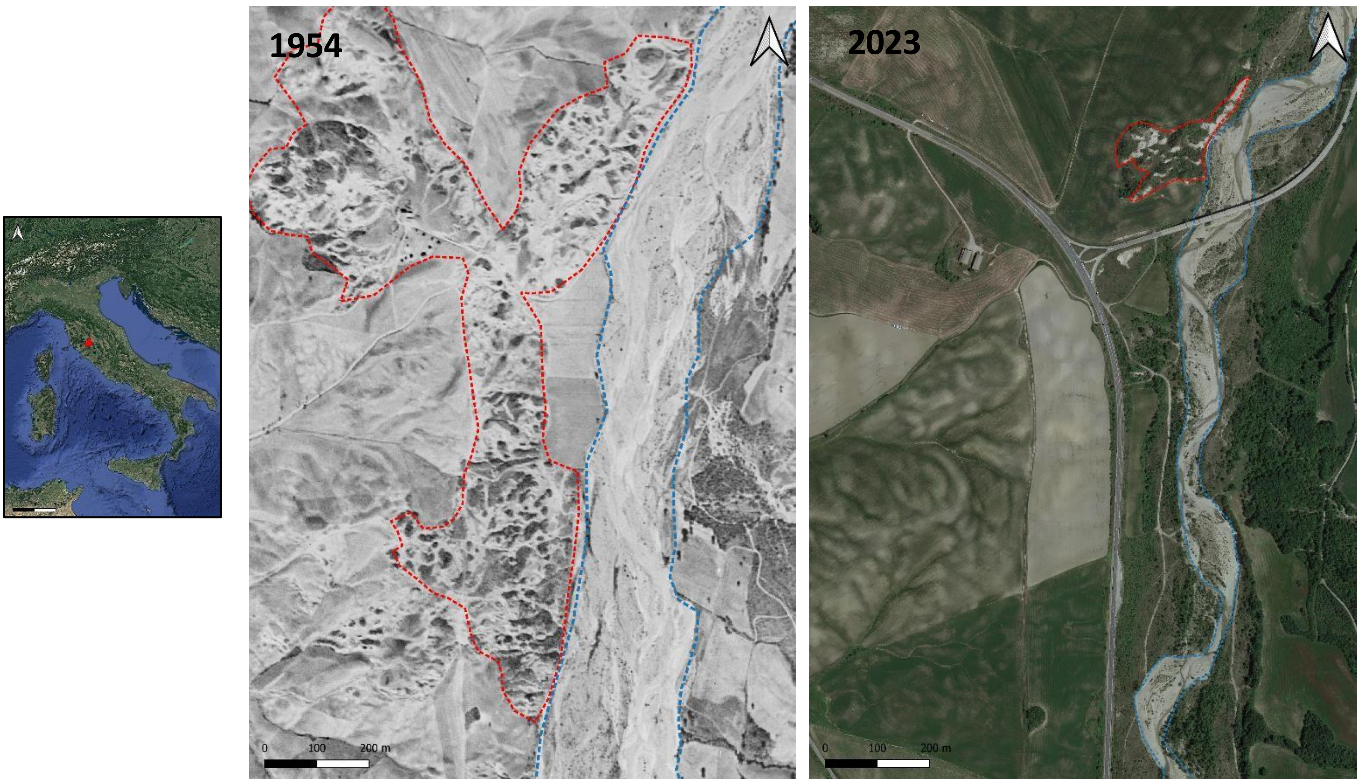

Figure 1: an example of how land use change, through badlands levelling, had modified the shape and width of riverbed between 1954 and 2023. The red line shows the badlands areas, which drastically reduced during the time while the blue one shows the riverbed adjustments.

Several studies well quantified the erosion rate in the residual badlands areas. First erosion monitoring studies applied traditional methodologies, such as metal stakes and historical aerial photos: long-lasting erosion monitoring datasets show 1-2.5 cm/year of average erosion rates in badland hotspots (Della Seta et al., 2007); in more recent research more sophisticated methods like digital photogrammetry were used (Aucelli et al., 2016; Stark et al., 2022). In addition, land use historical modifications were reconstructed at basin or hillslope scales (Torri et al., 2013; Amici et al., 2017). An important step forward in the study of such a representative sub-humid badlands landscape could be the generalization of the erosion patterns in areas not yet monitored. Moreover, the selection of a study area that takes into account the specific pressure may be more useful for land management since these areas still show the effects of past impacts and current pressures.

2. Research objectives, implications and applications

The general objective of the proposed research is the understanding the effects of land use changes on the recent erosion dynamics in Mediterranean badland areas.
The specific goal is a general erosion susceptibility model, by remote sensing and machine learning approaches, for a badlands landscape, modified by reclamation processes and land use changes, located in Tuscany (Italy).

The development of a general erosion susceptibility model will increase the ability to predict the effects of global changes for the future scenarios and could simplify the examination of erosion dynamics in areas where: i) fieldwork is challenging to conduct, ii) stakeholders, such as universities, municipalities, and government bodies, lack access to cutting-edge technology, iii) there is a need for rapid and cost-effective results.
One valuable improvement of this model involves upscaling the spatial resolution from a slope-based assessment to the catchment level, thereby enhancing its overall versatility and applicability.

3. Work plan and milestones

The research activities are planned at two different spatio-temporal scales (Task 1 and 2), preparatory to the development of the erosion susceptibility model (Task 3).

- TASK 1 - BASIN-SCALE LANDSCAPE MODIFICATION ANALYSIS (long term analysis)

PERIOD: First year – I Semester

ACTIVITIES: the main land use changes spanning 150 years will be detected, based on remote sensed data and multitemporal maps and aerial photographs. Satellite imagery and land use datasets, such as vegetation indices like NDVI and the CORINE Land Cover dataset, will help to reconstruct the main landscape modifications and to map the main changes in the distribution of erosion landforms during the last decades. Moreover, a literature review focusing on the relationship between soil erosion and land use changes, particularly within the study areas, will be carried out. Two residual badland areas will be selected for the short-term scale erosion monitoring with UAV-image based multitemporal surface reconstructions (Task 2).

MILESTONES TASK 1:

MS1.1 Multitemporal analysis of Normalized Difference Vegetation Index (NDVI) and Land Use and Land Cover (LULC)

MS1.2 Multitemporal morphodynamics analysis

MS1.3 Identification of the two studies areas for task 2.

- TASK 2 – HILLSLOPE SCALE HIGH RESOLUTION PHOTOGRAMMETRY (short term analysis)

PERIOD: First year – I and II semesters / Second year – III semester

ACTIVITIES: high-resolution photogrammetry will be applied in the selected study areas, during semi-annual drone surveys to capture erosion rates and landforms. It is assumed that the survey will carry out in Spring 2024, to catch the topographic predisposing factors before the erosion dynamics, and in Summer 2024, in order to obtain the effect of spring erosion dynamics. The selection of March 2024 and June 2024 as months able to describe the pre-and-post

erosion dynamics is based on historical mean precipitation data (1993-2023), with March representing a low-precipitation month and May representing a high-precipitation month. Then, at the Catholic University of Eichstätt-Ingolstadt (Germany), where a visiting period will take place, a multitemporal structure-from-motion Digital Elevation Model (SfM-DEM) will be created, and their comparison will allow to map and quantify the effects of the main erosion processes. Additionally, various high resolution topographic predisposing factors will be extracted, including lithology, curvature, slope, and others. The occurred erosion dynamics will be characterized.
In case major changes do not occur in spring, additional surveys during the III semester of the second year will be planned to catch the effects of autumn rainfall.

MILESTONES TASK 2:

MS2.1 Field survey activity

MS2.2 Elaboration of photogrammetry and remote sensing results

MS2.3 Structure of erosion database in GIS environment

- TASK 3 – EROSION SUSCEPTIBILITY MODELLING

PERIOD: Second year and Third year

ACTIVITIES: The evaluation of the erosion susceptibility in both study areas will be undertaken through the application of Machine Learning techniques. These techniques will determine the significance of individual factors, both topographic and environmental that influence erosive dynamics, analyze their interrelationships, and facilitate the implementation of an erosion model for the areas under investigation, taking into account various scenarios:
i) first scenario: the area 1 will be used both as training and testing area;
ii) second scenario: the area 1 will be used as training and the area 2 will be used as testing area;
iii) third scenario: the area 2 will be used as both for training and testing area;
This approach will allow for the evaluation of whether the erosion model developed for Area 1 can effectively predict erosive dynamics in Area 2, thereby demonstrating its potential for generalization. Scenario 3 serves as a validation test for the model generalization. If Scenario 2 yields results consistent with those of Scenario 3, the model will be validated, and a comprehensive general erosion susceptibility model will be established.

A second challenging specific goal will be the application of the validated susceptibility procedure to an agricultural hillslope affected in the past by land reclamation and badland levelling and now affected by gully erosion.

MILESTONES TASK 3:

MS3.1 Definition of the relative importance of individual predisposing factors

MS3.2 Definition of the correlation among the predisposing factors

MS3.3 Elaboration of model of erosion susceptibility for three scenarios

MS3.4 Validation of general erosion models of susceptibility

4. Training activities

Course	Period
Sapienza transversal training program on soft skills – Scientific calculation tools and Big data: Introduction on ML/DL and to Pytorch, From linear Regression to Deep Models using Neural Networks,	30 Nov, 1 December 2023
Workshop at the British Society for Geomorphology (UK) about: training in project management, dealing with large data sets, fieldwork, lab and numerical modelling, gaining funding as well as publication and future career development	4-7 December 2023
Attend course supply by Earth Sciences department for PhD student: Into to Matlab, GIS application, Data Analytics for Earth Sciences	November 2023 – February 2024

5. Mobility abroad

Period	Place	Activity
April 2024 – September 2024	Catholic University of Eichstätt-Ingolstadt (KU) - Germany	Analysis of photogrammetric data obtained from multitemporal surveys with drone with the aim of obtaining high resolution Digital Terrain Models (DEM) from which to extract maps of topographic predisposing factors.

6. Dissemination plan

Product	Date and Place	Audience	Content
Poster	Vienna, 14-19 April 2024	European Geoscience Union	Presentation of long-term analysis
Oral presentation	Rome, 23-26 September 2024	4th Workshop DENUCHANGE Workshop (IAG)	Presentation of photogrammetric result
Oral presentation	New Zealand, 9-13 February 2026	11th International Conference of Geomorphology	Presentation of general erosion model
Possible Paper 1	2024/2025	Academic journals	Short term analysis
Possible Paper 2	2024/2025	Academic journals	Long term analysis
Possible Paper 3	2025/2026	Academic journal	General erosion susceptibility model

7. Gantt chart

Activity	% completion task	*First year*		*Second year*		*Third year*	
		I Sem.	II Sem.	III Sem.	IV Sem.	V Sem.	VI Sem.
RESEARCH ACTIVITY							
- *Literature review*	0%						
- *Task 1 - Basin scale analysis*	0%						
- *Task 2 - Hillslope scale high resolution photogrammetry*	0%						
- *Task 3 - Erosion susceptibility modelling*	0%						
TRAINING ACTIVITY							
- *Sapienza transversal training program on soft skills*	0%						
- *Workshop at the British Society of Geomorphology (UK)*	0%						
- *Attend course supply by earth sciences department*	0%						
MOBILITY ABROAD ACTIVITY							
- *Visiting at Catholic University of Eichstätt-Ingolstadt (Germany)*	0%						
DISSEMINATION ACTIVITY							
- *Poster at European Geoscience Union, Vienna*							

- *Presentation at the 4th workshop DENUCHANGE - Rome, Italy*	0%						
- *Presentation at the 11th International Conference of Geomorphology*	0%						
- *Papers publication*	0%						

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