Connecting Present and Future Soil Erosion Risk in the Upper Tagus River Region of Portugal

António Canatário Duarte[1,2,3](✉), Luís Quinta-Nova[1,2,3], and Carmo Horta[1,3]

[1] Polytechnic Institute of Castelo Branco, School of Agriculture, Quinta da Senhora de Mércules, 6001-909 Castelo Branco, Portugal
acduarte@ipcb.pt
[2] GEOBIOTEC, Calçada Fonte do Lameiro 6,, 6200-358 Covilhã, Portugal
[3] CERNAS-IPCB, Polytechnic Institute of Castelo Branco, Quinta da Senhora de Mércules, 6001-909 Castelo Branco, Portugal

Abstract. Soil water erosion causes soil degradation, affecting its fertility and, consequently, leading to the loss of its productive capacity and may contribute to a process of desertification. Countries in the Mediterranean basin are under the influence of a climate pattern that is unfavorable to maintaining effective soil cover, with peak precipitation events occurring, and an increase in soil erosion rates is expected in changing scenarios. Climate, where the occurrence of extreme meteorological phenomena will be more frequent. The aim of this study is to evaluate the present situation and estimate the future soil erosion risk of in the upper region of the Portuguese part of the Tagus River basin, where agricultural use and livestock activities are dominant in soils that are highly susceptible to erosion. The soil loss estimation was carried out for the current situation and for the climatic conditions projected for 2050, considering two Representative Concentration Pathways (RCP 4.5 and RCP 8.5). We use the RUSLE methodology to determine the risk of soil water erosion. Although annual precipitation decreases for both RCPs, the erosivity index will increase in both scenarios. Our findings provide insights into the consequences of socioeconomic development options on physical land degradation and loss. To understand the process of soil water erosion, using modeling and other tools, is very important for the design of policy instruments that minimize the effects of climate change on soil.

Keywords: Climate change · Land cover · Rainfall · Soil loss

1 Introduction

The IPCC, in their report on climate change, highlights that the rise in global average surface temperature compared to pre-industrial levels can significantly impact land degradation processes, including soil erosion [1]. Mediterranean countries are especially vulnerable to erosion [2]. The rainfall concentration in the cold season in soils with poor

A. Çiner et al. (Eds.): MedGU 2023, *Recent Research on Environmental Earth Sciences, Geomorphology, Soil Science, Paleoclimate, and Karst*, pp. 3–8, 2025.
https://doi.org/10.1007/978-3-031-86866-5_1

crop cover and the expected increase of the rainfall peak events will contribute to a continuously increasing rate of soil erosion. In the EU, it has been estimated that the annual loss of agricultural productivity due to water-induced soil erosion is approximately 0.43% [3].

In Portugal, soil erosion is driven by various factors, including inappropriate land management practices, wildfires, and overgrazing. Agricultural land use is a significant contributor to high soil erosion rates [4]. In intensively grazed areas, soil erosion is further accelerated due to reduced vegetation cover and soil compaction caused by trampling [5]. Took place a slight reduction in soil erosion rates in Portugal between 2001 and 2012. This decline is linked to the expansion of vegetation cover, primarily due to the abandonment of farms during the global recession [6]. Portugal's average soil erosion rate for arable land is ~2.75 t ha^{-1} yr.$^{-1}$ [7]. it is projected that mean soil loss rates due to water erosion in agricultural areas of the European Union, including Portugal, may increase by 13–22.5% by 2050 compared to the 2016 baseline, emphasizing the importance of sustainable land management practices to mitigate erosion and preserve soil quality [8].

So, the primary aim of this study was to assess the current state and predict future trends in soil erosion rates within the Portuguese part of the Upper Tagus River basin, Portugal, in order to identify future changes in terms of soil loss, providing planners and decision-makers with data that allows them to make decisions aimed at mitigating the expected impacts.

2 Materials and Methods

The study area is located in the central-eastern part of Portugal, and includes the Tagus International Nature Park (PNTI) and the surrounding area belonging to the Tagus International Transboundary Biosphere Reserve, with an extent of 1692 sq. km (Fig. 1). It is an area with altitude ranging between 120 and 390 m, with steep relief as a result of the embedding of the Tagus and its tributaries on the edge of peneplain.

The climate is typical Mediterranean, sub-humid to dry, with mild winters and warm summers. The annual mean precipitation is about 600 mm yr.$^{-1}$, with peaks in autumn and winter. Very weakly developed mineral soils with a low content in organic matter are dominant in the region, mainly leptosols and regosols.

Most of the vegetation is made up of sclerophyllous formations of holm oak and cork oak, as well as abundant patches of scrub, which alternate with cultivated areas and pastures. In the park area are also present several plant communities typical of Mediterranean ecosystems classified as priority habitats by the EU Habitats directive.

The annual potential soil erosion rate, denoted as E (t ha^{-1} yr.$^{-1}$), was estimated using the Revised Universal Soil Loss Equation (RUSLE) according to the following equation [9]:

$$E = R \times C \times K \times LS \times P \tag{1}$$

where:

R (R-factor): This represents the erosivity factor due to rainfall and is quantified as MJ mm ha^{-1} h^{-1} yr.$^{-1}$. It characterizes the meteorological conditions influencing erosion, primarily driven by precipitation intensity.

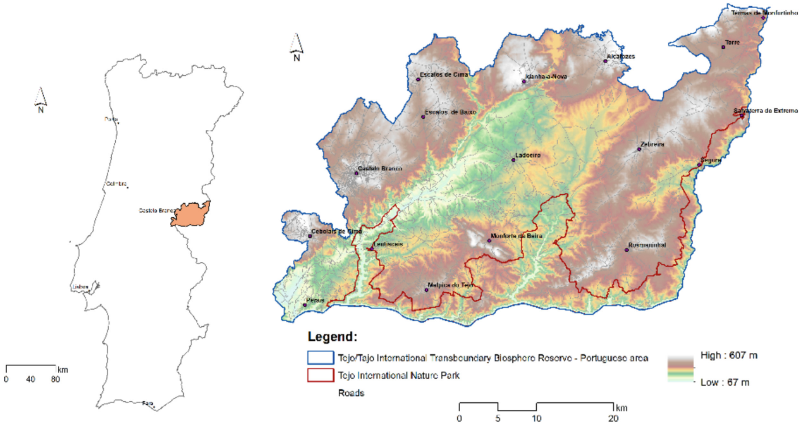

Fig. 1. Location of the study region

C (C-factor): The cover-management factor accounts for the protective role of land cover, particularly vegetation, against soil erosion. Lower C-factor values indicate better protection and reduced erosion risk.

K (K-factor): The erodibility factor expresses the vulnerability of soil to erosion, and is related to soil properties, measured in units of t ha h ha^{-1} MJ^{-1} mm^{-1}.

LS (LS-factor): Serves as a representation of the topographic attributes of a given area. It considers slope length and steepness, which have a direct impact on the potential for soil erosion.

P (P-factor): Evaluates the effectiveness of erosion control and land management practices in mitigating erosion.

To obtain data for the rainfall erosivity in the present and in future scenarios, we have considered the data from the last decade and from two representative concentration pathways (RCPs): RCP 4.5 and RCP 8.5, fitted for 2050, obtained from the dataset rainfall erosivity in Europe [10]. RCP 4.5 represents a probable baseline scenario, considering the limited availability of non-renewable fuels. Under this scenario, emissions are expected to peak around 2040 and then decrease. This would result in a global temperature increase of 1.1 to 2.6 °C by 2081–2100 compared to the 1986–2005 period. In contrast, RCP 8.5 represents a less favorable climate change scenario. Emissions are expected to increase continuously throughout the twenty-first century, leading to a more substantial global temperature increase of 2.6 to 4.8 °C by 2081–2100 [11].

Land cover data from 2018 and the predicted land cover of 2050, used to estimate the C-factor, were obtained from [12]. The soil data for the study area were obtained from [10] and were used to calculate the soil erodibility based on a table made available from the same source. The LS-factor was estimated from a raster DEM with a 25 m spatial resolution [13].

3 Results and Discussion

Figure 2 shows the annual potential soil erosion rate estimated for the study area for the present and future scenarios, considering a spatial resolution of 500 m.

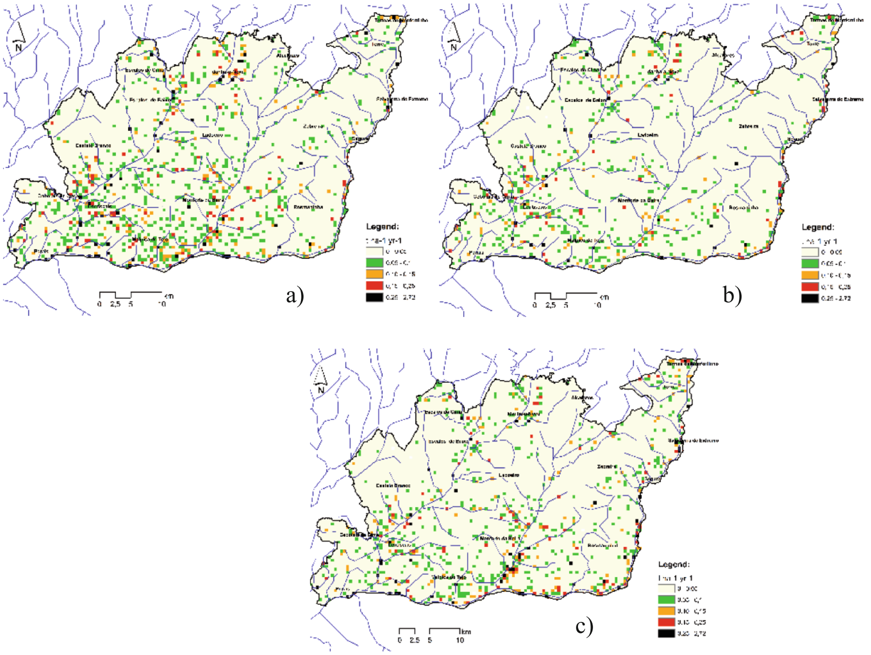

Fig. 2. Estimates of mean annual soil erosion rates: a) Present; b) RCP 4.5–2050; c) RCP 8.5–2050

Despite the average values of soil erosion being similar between the present situation (0.092 t ha^{-} $yr.^{-1}$ ± 0.0266), and both future scenarios RCP 4.5 (0.061 t ha^{-1} $yr.^{-1}$ ± 0.019) and RCP 8.5 (0.074 t ha^{-1} $yr.^{-1}$ ± 0.023), the highest values of erosion rate simulated by RUSLE model for the present situation and for the two studied scenarios show significant differences: 1.512 t ha^{-1} $yr.^{-1}$ (present), 1.946 t ha^{-1} $yr.^{-1}$ (RCP 4.5), and 2.668 t ha^{-1} $yr.^{-1}$ (RCP 8.5).

Comparing the present situation and predicted pathways of the annual potential soil erosion rate (Fig. 3), we verify that the erosion values increase for the RCP 8.5 pathway in 19% of the study area, with a highest difference of 0.532 t ha^{-1} $yr.^{-1}$. For the RCP 4.5 pathway, the erosion increases in 6% of the study area, with the highest increase of 0.283 t ha^{-1} $yr.^{-1}$. Our results align with the conclusions drawn in recent studies regarding the impact of climate change on soil erosion [6, 8].

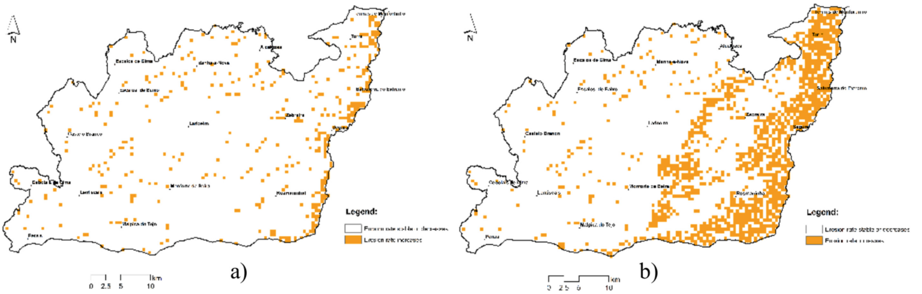

Fig. 3. Changes in soil erosion rates: a) present to 2050 (RCP 4.5); b) present to 2050 (RCP 8.5)

4 Conclusion

The use of global models, such as RUSLE, to create spatial associations between climate change, soil erosion, and alterations in land cover is essential for improving spatial management strategies. These models play a crucial role in this enhancement. Both studied scenarios anticipate a slight increase in the soil erosion rate. Even in the least aggressive scenario, the soil erosion will increase in 6% of the study area, with a maximum increase of 0.283 t ha^{-1} $yr.^{-1}$. For the most unfavorable scenario, the maximum increase in the mean soil erosion rate will be 0.532 t ha^{-1} $yr.^{-1}$, verified in 19% of the total area of this study. These findings call for considering the necessity for better soil management practices due to the vulnerability of this type of soils to water erosion, and, although erosion rates are not very high, we must always bear in mind that the class of particles preferentially lost are those with the greatest importance in soil properties.

Acknowledgements. This work is supported by FCT - Foundation for Science and Technology, I.P., under the project UIDB/00681/2020.

References

1. Masson-Delmotte, V., et al.: Special Report on Climate Change and Land. Intergovernmental Panel on Climate Change, Geneva, Switzerland (2020)
2. Arar, A., Chenchouni, H.: A simple geomatics-based approach for assessing water erosion hazard at montane areas. Arab. J. Geosci. **7**(1), 1–12 (2014)
3. Panagos, P., Standardi, G., Borrelli, P., Lugato, E., Montanarella, L., Bosello, F.: Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. Land Degrad. Dev. **29**(3), 471–484 (2018)
4. Nunes, A., Almeida, A., Coelho, C.: Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. Appl. Geogr. **31**, 687–699 (2011)
5. Kosmas, C., Detsis, V., Karamesouti, M., Kounalaki, K., Vassiliou, P., Salvati, L.: Exploring long-term impact of grazing management on land degradation in the socio-ecological system of Asteroussia mountains, Greece. Land. **4**(3), 541–559 (2015)
6. Borrelli, P., et al.: Land use and climate change impacts on global soil erosion by water (2015-2070). Proc. Natl. Acad. Sci. **117**, 21994–22001 (2020)

7. Panagos, P., et al.: A soil erosion indicator for supporting agricultural, environmental and climate policies in the European union. Remote Sens. **12**, 1365 (2020)
8. Panagos, P., et al.: Projections of soil loss by water erosion in Europe by 2050. Environ. Sci. Policy. **124**, 380–392 (2021)
9. Renard, K.G.: Predicting soil erosion by water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). United States Government Printing, Washington, DC (1997)
10. European Soil Data Centre. https://esdac.jrc.ec.europa.eu. (2022). Accessed 27 June 2022
11. Collins, M., et al.: Long-term climate change: Projections, commitments and irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate. Change Cambridge University Press, Cambridge, United Kingdom and New York, USA (2013)
12. ESRI. https://livingatlas.arcgis.com/landcover-2050.(2022) Accessed 29 June 2022
13. European Environment Agency. https://www.eea.europa.eu/data-and-maps/data/eu-dem. (2022) Accessed 22 June 2022