Post-fire Soil Erosion Risk in Portugal– Prediction, Validation and Uncertainties of a Nation-wide MMF Application

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Abstract

Wildfires are a recurrent and increasing threat in mainland Portugal, where over 4,5 million hectares of forests and scrublands have burned over the last 38 years. These fire-affected landscapes have suffered an intensification of soil erosion processes, which can negatively affect soil carbon storage, reduce fertility, forest productivity, and become a source of pollutants. The main objective of the present study is to produce a post-fire soil erosion risk map for the forest and scrubland areas in Mainland Portugal and assess its reliability. To this end, the semi-empirical Morgan–Morgan–Finney erosion model was used to assess the potential post-fire soil erosion according to distinct scenarios (burn severity and climate), and the accuracy of the predictions was verified by an uncertainty analysis and validated against independent field datasets. The proposed approach successfully allowed mapping post-fire soil erosion in Portugal and identified the areas with higher post-fire erosion risk for past and future climate extremes. The outcomes of this study comprise a set of tools to help forest managers in their decision-making for post-fire emergency stabilization, ensuring the adequate selection and implementation of mitigation measures to minimize the economic and environmental losses caused by fire-enhanced soil erosion.

1. Introduction

Soils are one of the most valuable non-renewable Earth resources, containing the largest terrestrial organic carbon stock and supporting natural vegetation as well as human agroforestry-ecosystems¹. In the last decades, due to several causes such as unsustainable land use and management^{2–5} and climate change⁴, land degradation risk has become one of the most important ecological concerns worldwide^{6,7}.

The propensity of Portugal to the occurrence of extreme weather and climate conditions, such as heatwaves and droughts^{8,9}, makes it the first southern European country in terms of the number of wildfire events, and the second in terms of the total burned area¹⁰. Therefore, wildfires constitute one of the most significant environmental problems in Portugal, and are frequently considered as an important driver of forest soil erosion and land degradation^{11,12}. Besides the destruction of vegetation and litter cover that intercepts and protects the soil from direct rainfall impacts, wildfires cause soil heating that, in turn, can reduce soil's aggregate stability, decrease porosity, induce water repellency and decrease infiltration^{11,13,14}. The combination of these direct wildfire impacts on vegetation and soil negatively affects the forests services, including the water cycle regulation and the soil erosion control¹⁵. Also, fire-enhanced runoff and erosion responses are well documented to have important off-site consequences such as contamination of the downstream water bodies by eroded sediments and wildfire ashes¹⁶, or the occurrence of destructive debris flows¹⁷ at lower rainfall thresholds.

Consequently, rehabilitation treatments have been a priority in post-fire forest management, also motivated by the increasing allocation of European funding for the implementation of post-fire erosion mitigation measures¹⁸. However, a timely implementation of these measures has often been compromised by the lack of methodologies providing an early diagnosis of the areas with higher soil

erosion risk within a short timeframe following the wildfire¹⁹. To address such difficulties, soil erosion modelling arises as a powerful tool, providing crucial information to support decision-making, both for emergency responses and long-term planning²⁰.

In the last twenty years, there has been an increasing number of studies testing different models for post-fire soil erosion predictions²⁰ and adapting them to accommodate fire-induced changes in vegetation, soil, and water infiltration. Most of those adaptations are based on the degree of burn severity, motivated by the numerous evidences of its key-role in post-fire soil erosion¹¹. One of the most frequently tested models is the revised Morgan-Morgan-Finney model (MMF), especially for burned areas in Portugal^{20–22} and NW Spain²³. Although MMF has performed well in predicting erosion measured in field studies, there is still an urgent need for a simple-to-use model-based tool to support decision-making in post-fire management. In addition, a recent study²⁰ stressed that in spite of recent advances made in post-fire soil erosion modelling, they have typically overlooked model validation against independent datasets as well as model uncertainty analysis. The outcomes of uncertainty analysis constitute vital importance for forest managers to identify and prioritize intervention areas and make informed decisions²⁴ on where and when to best use their typically scarce resources for an optimised emergency stabilization²⁰.

The present study aims to develop and validate a map of soil erosion risk over the first post-fire year for mainland Portugal (hereafter, Portugal) and assess its uncertainties. This was accomplished using the revised MMF model for the three land cover classes in Portugal that have been most frequently affected by wildfires (*eucalypt*, pine, and scrubland)²⁵. Two main sources of uncertainty were considered, i.e., i) those related to the post-fire rainfall regime, by using two distinct rainfall datasets (ERA-Interim and ERA5) from the European Centre for Medium-Range Weather Forecasts; ii) those related with fire severity, using three distinct scenarios of soil burn severity. The reliability of the erosion risk map was assessed by comparing the MMF predictions against independent erosion data from several field trials conducted in Portugal during the 2005–2017 period. This study seeks to answer the specific research questions: (i) “Can the revised MMF model be used as a tool to determine post-fire soil erosion risk in Portugal and to support decision-making in post-fire emergency stabilization?”; (ii) “How important are the model input data for accurately predicting post-fire soil erosion risk, and how can this selection affect decision-making in post-fire management?”.

2. Materials And Methods

In this study, we developed a post-fire soil erosion risk map for Portugal using the revised MMF model, by applying a successful field-based parameterization that addressed different burn severities and land uses^{21,22,23}. This map’s development required several steps of data processing, in order to accommodate variables from different sources to the same spatial resolution and to the model input requirements. Afterwards, we computed the revised MMF model for the 38 hydrological years between October 1st 1980 and September 30th 2018, using two different rainfall datasets and for three different soil burn severity scenarios. Erosion predictions were classified according to the six soil erosion by water classes defined

by the Joint Research Center²⁶: [0; 0.1]; [0.5; 1]; [1; 2]; [2; 5]; [5; 10]; $\geq 10 \text{ Mg ha}^{-1} \text{ y}^{-1}$. Finally, we performed an uncertainty analysis and validation assessment to the chosen modelling approach, by comparing our results with average field soil erosion assessments and associated local precipitation measurements.

The inputs for the revised MMF model consisted mostly of spatially distributed data characterizing topography, soil properties, soil moisture content, and rainfall regime. Additionally, field data, which were considered as reference data, were collected and used for model performance evaluation and uncertainty analysis.

2.1. Study area

Portugal is located in Southwestern Europe with a total area ca. 900,000 km², and an altitude ranging from sea level in the western and southern coastal areas to about 2,000 m a.s.l. in the north-central region (Fig. 1)^{9,27}. It is located in a transition zone between sub-tropical and mid-latitude climates⁸, where temperate climate prevails with dry and warm summer (Csb) in the north, and with dry and hot summer (Csa) in the south²⁸. The type of climate depends on the topographical features of the country and helps explaining the land cover differences among regions (Fig. 2). Those climate conditions increase the wildfire susceptibility of Portugal, and explains the prominent annual wildfire activity cycle (Fig. 1)⁹.

2.2. Spatially distributed datasets

A high-resolution map of slope angle was derived from the Digital Elevation Model²⁹ that resulted from the Shuttle Radar Topographic Mission at a resolution of 1 arc-second. The map showed a heterogeneous slope steepness distribution within Portugal, observing the highest values in the north and southernmost regions (Fig. 2).

Soil bulk density was obtained from the European Soil Data Centre dataset³⁰ at a resolution of 250 m, and soil moisture content was obtained from European Space Agency³¹ at a spatial resolution of 21 km grid.

Land cover national information was obtained from the national inventory of 2018 provided by *Direção Geral do Território*³². It comprises 83 land cover sub-classes but, given the focus on wildfires, we only used five (Table 1), which is justified on the section above. Together, these 5 sub-classes correspond to about 3,3 million ha, which comprises 63% of the main forest types of Portugal and all of its scrublands³³. The forests dominated by eucalypt (*Eucalyptus spp.*) and maritime pine (*Pinus pinaster* Ait.) are mostly located in Central Portugal (Fig. 2), while the stone pine (*Pinus pinea* L.) forests are mainly located immediately to the south of the Tagus river (Fig. 2). The scrublands are the dominant land cover in the northeastern and southernmost regions of Portugal.

Table 1

Land cover map 2018 inventory sub-classes used in this study, and their area³².

Land use and occupation charter 2018 inventory sub-classes	Area (ha)	% of total forest
Eucalypt (<i>Eucalyptus spp.</i>) forest	928,211	27
Maritime pine (<i>Pinus pinaster</i> Ait.) forest	1,020,283	29
Stone pine (<i>Pinus pinea</i> L.) forest	211,147	6
Other softwood forests	37,213	1
Scrublands	1,107,546	-

2.3. The rainfall datasets

The gridded global atmospheric reanalysis products of the European Centre for Medium-Range Weather Forecasts ERA-Interim and ERA5 datasets (80 km and 31 km grid resolution, respectively) were selected to obtain annual rainfall data (Fig. 3). Both datasets were selected because MMF requires as input a continuous series of daily precipitation data^{34,35}.

The Soil bulk density, soil moisture content, Era-Interim and ERA5 datasets needed to be scaled down to fit the grid dimension of the slope angle dataset (25 m). To this end, the Inverse-Distance Weighting method (IDW) was used, which is a spatial interpolation deterministic model that was computed using R gstat package³⁶. However, since Era-Interim can be retrieve from the source with 25m, only the others three datasets were scaled down.

2.4. Reference soil erosion and local precipitation

MMF performance as well as the global rainfall data sets were validated against published field observations. To this end, the SCOPUS data base was searched to compile all peer-reviewed articles in English in international journals that reported annual post-fire erosion rates in Portugal. The resulting 11 articles concerned a total of 10 field sites with micro-plot to swale-scale erosion data on 3 to 18 plots per site, giving a total of 20 years of study (Table 2). The articles also reported the relevant rainfall data for all 10 sites. There was a strong bias in the geographical location of the field sites, the bulk of them being located in north-central Portugal. This bias, however, largely coincides with the strong prevalence of burned areas in north-central Portugal over the past decades (Fig. 1).

Table 2
Description of the field sites and experimental designs used for validation of post-fire soil erosion predictions by MMF.

Location, Municipality ^{reference}	Coordinates	Monitoring years	Nr. erosion plots	Plot size (m ²)	Annual rainfall (mm)
Açores, Albergaria - a - Velha ³⁷	40°40'46.62"N 8°26'54.80"W	2005 - 2006	8	0.25	1048 - 1608
Colmeal, Góis ³⁸	40°08'42"N 7°59'16"W	2008 - 2010	3*	10	
Colmeal, Góis ^{22,39}	40°08'48"N 7°59'50"W	2008 - 2012	16	0.25– 0.5	833 - 1534
Pessegueiro do Vouga, Sever do Vouga ⁴⁰	40° 43'05"N 8° 21'15"W	2007	6*	16	1546
Ermida, Sever do Vouga ⁴¹	40°44'05"N 8°21'18"W	2010	4*	0.25	1475
Ermida, Sever do Vouga ³⁷	40°44'05"N 8°21'18"W	2010	3*	100	1475
Montesinho, Bragança ⁴²	41°53'57"N 6°40'55"W	2011	6	4	545
Várzea, Viseu ⁴³	40°45'58"N, 7°51'35"W	2012 - 2013	18	0.25	1289–1628
Semide, Miranda do Corvo ⁴⁴	40°09'57"N 8°19'31"W	2015 - 2016	3	16	1291
Semide, Miranda do Corvo ⁴⁵	40°09'57"N 8°19'31"W	2015 - 2017	3	1000	1291

2.5. Post-fire soil erosion predictions by the MMF model

The MMF model predicts annual runoff and associated soil losses at slope scale²², separating the processes in a water phase and a sediment phase⁴⁶. The first phase simulates overland flow generation as well as detachment of soil particles by rainfall and runoff, while the second phase models the transport capacity of the overland flow to transport the detached soil particles^{22,46}. In this study, MMF was applied to predict annual soil losses for the study period, and doing so for three scenarios of soil burn severity (low, moderate, high). The maximum annual erosion rates predicted over this 38-year period were then used for mapping post-fire erosion risk. The MMF parameters and associated model input data sets were the following:

1. Annual rainfall and days with rain: derived from the two above-mentioned global rainfall datasets (mm yr^{-1} and number);
2. Soil parameters: bulk density (BD , g cm^{-3}), effective hydrological depth of soil (EHD, m), soil detachability index (K , g J^{-1}), and cohesion of the surface soil (COH, kPa), estimated from LUCAS dataset³⁰, field data^{14,39}, and previous modelling work by the authors^{21–23};
3. Landform: represented as slope steepness (S , $^{\circ}$);
4. Land cover parameters: rainfall interception (A), ratio of actual (E_t , mm) to potential (E_0 , mm) evapotranspiration, crop cover management factor (C), canopy cover (CC , %), ground cover (GC , %), and plant height (PH , m); estimated from previous applications of MMF by the authors in recently burned areas in north-central Portugal^{21–23};
5. Maximum soil moisture at storage capacity: estimated from soil moisture database.

2.6. MMF uncertainty analysis and validation

The parametric uncertainty analysis of the MMF erosion predictions was performed with respect to the rainfall input data. To this end, the predictions resulting from the ERA-Interim and ERA5 datasets were compared, in terms of total predicted soil losses, magnitude and spatial discrepancies. In addition, MMF performance was assessed by comparing the predicted and observed post-fire erosion rates for the 10 field sites listed in Table 2). This was done using the rainfall data from the two global rainfall data sets as well as from the field studies. To quantify MMF performance, the following four indicators were used in line with previous studies^{21,22,47}:

1. Root mean square error (RMSE) that represents the measure of the predicted variation to observed data;
2. Nash–Sutcliffe efficiency (NSE), which expresses the magnitude of the residual variance relative to the variance in the measured data;

3. Coefficient of determination (R^2), which explains how well a model performs when replicating the observed outcomes;
4. Percent bias (PBIAS), which expressed the degree to which predicted values underestimate (negative PBIAS) or overestimate (positive PBIAS) the observed values.

It should be noted, however, that such metrics are more frequently used within continuous catchment hydrology modelling approaches rather than spatially distributed predictions⁴⁷. Despite those limitations, such methodology is still the best one to assess model performance and model adaptation.

3. Results

3.1. Post-fire soil erosion risk mapping

The nation-wide application of the MMF model to Portugal revealed substantial differences in terms of predicted soil erosion amounts based on the rainfall dataset choice (Fig. 4). For the entire period of predictions (1980 to 2018), the highest soil erosion predictions were found for the year 2001, amounting to a total of 6,854,429 and 210,317 $\text{Mg ha}^{-1} \text{yr}^{-1}$ of soil loss under severe burning conditions for the ERA-Interim and ERA5 rainfall datasets, respectively. The corresponding post-fire soil erosion risk map revealed that, according to ERA-Interim, 55.7% of the studied area would be at serious risk of soil losses in case of a severe wildfire ($> 10 \text{ Mg ha}^{-1} \text{yr}^{-1}$), while for ERA5 that erosion risk class would be present in only 0.1% of the study areas.

Nevertheless, in both cases the highest post-fire soil erosion risk classes are predominantly found in North-Central Portugal, coinciding with a greater distribution of steep slopes (Fig. 2) and high rainfall amounts (Fig. 3), over areas with Scrublands and *Eucalyptus* as dominant vegetation cover (Fig. 2).

When considering the effect of burn severity in our modelling predictions, it is noteworthy that soil burn severity dramatically increases sediment losses, being this aspect more evident for ERA-Interim than for ERA5 (Fig. 4). For low burn severity, predicted soil losses are mostly (99.9%) below the $10 \text{ Mg ha}^{-1} \text{yr}^{-1}$ threshold for ERA - Interim, while for ERA5 this limit decreases $1 \text{ Mg ha}^{-1} \text{yr}^{-1}$. For moderate burn severity conditions, the areas with predicted post-fire erosion risk above the threshold of $10 \text{ Mg ha}^{-1} \text{yr}^{-1}$ substantially increased for the North of Portugal using the ERA-Interim dataset, while for ERA5 these rates are still below. For high burn severity, 14% of the target area presents a severe risk of post-fire soil erosion, with rates above $50 \text{ Mg ha}^{-1} \text{yr}^{-1}$ for the ERA-Interim dataset, and predominating 1 to $2 \text{ Mg ha}^{-1} \text{yr}^{-1}$ classes for the ERA5 dataset.

3.2. Model uncertainty analysis and validation

Our results show that, for the high burn severity scenario, soil erosion predictions obtained using the ERA-Interim data set are two orders of magnitude higher than those using the ERA5 data set. Despite the fact that the spatial distribution of rainfall of both databases presents slight differences (Fig. 3), no major

spatial discrepancies were found when predicting post-fire soil erosion (Fig. 5); being the ones resulting from ERA-Interim consistently higher than those from ERA5 because of its almost consistently higher annual rainfall amounts, with the exception of few locations (0.002%).

Overall, the MMF predictions for the field sites presented a poor agreement with the observed average post-fire erosion rates despite the high variability observed in such field measurements (Table 3; Fig. 6). In terms of all four indicators, MMF performance was not satisfactory for any of the four rainfall data sets, at least according to the thresholds proposed in Moriasi *et al.*⁴⁷. Nonetheless, MMF performance did differ noticeably between the four data sets. Overall, it was best when using the local rainfall data combined with the ERA-interim rainfall data, and worst when using the ERA5 data set. Furthermore, the use of local rainfall data generally improved model performance for the two global rainfall data sets, except in terms of PBIAS in the case of the ERA-Interim data set and in terms of R2 in the case of the ERA5 data set. Finally, MMF performance was markedly better for the ERA-Interim data set than for the ERA5 data set, in terms of all four indicators. The ERA5 data set leads to much stronger underestimation of observed erosion rates than the ERA-Interim data set, as is also easily perceived in Fig. 7.

Table 3

MMF performance metrics for the prediction of annual post-fire erosion rates observed at 11 field sites for four different rainfall data sets. NSE: Nash-Sutcliffe Efficiency; PBIAS: Percent Bias; RMSE: Root Mean Square Error; R2: coefficient of determination.

Model performance indicators	ERA Interim	ERA Interim & local rain	ERA5	ERA5 & local rain
NSE	0.09	0.26	-0.67	-0.36
PBIAS (%)	-52.6	-78.5	-194	-126
RMSE (Mg ha ⁻¹ yr ⁻¹)	2.40	2.16	3.25	2.94
R ²	0.40	0.40	0.33	0.24

4. Discussion

This study aims to produce a soil erosion risk map for the most wildfire-prone vegetated areas in Portugal²⁵ by using the revised MMF model, which has been previously calibrated for Portugal^{21,22} and NW Spain²³ and has demonstrated great capacity to simulate annual and seasonal the hydrological and erosive response in recently burned forest areas^{21,22,48}.

As a final outcome of this study, such post-fire soil erosion risk map for Portugal was possible to be created with the data available data, although several important uncertainties were identified while its development. Nevertheless, given the uncertainty analysis and the model performance assessment made

with the local validation sites, the ERA-Interim originated predictions under the high severity scenario presents itself as the best map to be used when assessing post-fire soil erosion risk (Fig. 8).

Despite post-fire soil erosion reaches the highest risk ($> 10 \text{ Mg ha}^{-1} \text{ y}^{-1}$) in both north and south of Portugal, the density of target areas with such risk is much higher at the north-central part of the country (Fig. 4). This can be justified by the great cover of *eucalypt*, *pine* and scrubland areas (Fig. 2), and the highest distribution of steep slopes at these locations. Such result also agrees with previous studies, whereas although⁴⁹ shows a different rainfall input in the form of rainfall erosivity, and the soil erosion risk obtained for Europe with revised universal loss equation (RUSLE) model presents a similar spatial pattern as the one obtained in this study^{26,50}.

Such result implies that in order to prevent post-fire soil erosion in recently burned areas, the decision-makers and land managers of the areas located at the north-central region of Portugal need to be aware of such risks. Especially considering that those areas at higher risk are recurrently affected by wildfires as presented by the historical data (Fig. 1), and that these same locations also provide important ecosystems services to society such as the maintenance of water quality and flood control, which can be severely affected by post-fire soil erosion^{16,51,52}.

To help managers in the decision-making process after wildfires, this map (Fig. 6) can be used for the identification of the areas with higher soil erosion risk and thus, of priority for intervention, ensuring the most efficient implementation of post-fire mitigation measures¹⁹. Should be highlighted however, that the transformation of the predictions obtained in this study to an easily accessible tool for post-fire management would further improve decision-making in these high-risk areas, by considering the various scenarios of severity and the specificities of each affected area in a dynamic way.

A parametric uncertainty analysis was performed to be used as a guideline in the decision-making process when the purpose is to consider and apply, on time, the proper soil erosion mitigation measures after wildfire. Taking this in mind, the methodology used to create the predictions was practical, scientifically defensible and robust enough to be applicable. For validation matters, several field data were considered as the best estimation possible of the post-fire soil erosion rates.

The differences between the predictions from ERA-Interim and ERA5 (Fig. 5) underline that different precipitation datasets can contain significantly different spatiotemporal information, which might lead to the production of contrasting soil erosion estimations. Also, the authors acknowledge that these discrepancies might be from the limitations of IDW used to scaled down ERA5, which is in spite of being simple, fast and easy to compute and to interpret⁵³, has some limitations such as: (i) weighting parameters are chosen *a priori*, and not empirically; (ii) the variances of predicted values in unsampled locations cannot be estimated; and (iii) the IDW standard application assumes that the distance-decay relationship is constant through space. In this respect, it is important to underline the good agreement between total annual mean precipitation results obtained in this study with ERA-Interim for 1980–2018

period (Fig. 3) and the maps published in the Iberian climate Atlas produced with data observed in a large set of weather stations, although for a slightly different (1971–2000) period⁵⁴.

Finally, the authors acknowledge that biases of the reanalysis may affect the agreement between the soil erosion predictions and soil erosion measurements when using this data as surrogates of observations. In addition to that, some limitations were also found concerning the available methodologies to assess model performance, especially for validation purposes. By using Moriasi *et al.*⁴⁷ metrics, only average soil erosion measurements were used, which did not account for the high variability of field results. Notwithstanding, ERA-Interim seems to be the most advisable reanalysis product since it produced the best results (Fig. 6), despite the underestimations found when compared with the field validation data. Which is in line with⁵⁵, who have demonstrated that ERA-Interim underestimates precipitation in the rainiest months in Western Iberia and tends to overestimate it in NE and SE regions. This means that when creating risk maps, authors should consider more than one source of data in order to account for additional uncertainties in the predictions, as well as taking into account for local data when available in order to better evaluate model performance. Those considerations would eventually translate into more detailed and accurate risk maps, and better informed land management decisions²⁴. Nevertheless, we believe that despite those discrepancies, from the management point of view, the created post-fire soil erosion risk map is of great value as an early-diagnosis tool for Portuguese forest land managers.

Moreover, should be highlighted that wildfire occurrence is not exclusive from the Portuguese territory and corresponds to a global environmental problem⁵⁶, and therefore the extension of such approach should be considered at the European or Global scale.

5. Conclusions

This study produced a soil erosion risk map for the most fire-prone vegetated areas in Portugal (Eucalyptus, Pine, and Scrubland), based on the revised Morgan – Morgan - Finney model predictions and validated using local post-fire field data, which, to the best of our knowledge, has never been done for Portugal.

The main conclusions drawn while developing this study can be summarized as follows:

- a. the highest post-fire soil erosion risk is estimated in north-central Portugal, and land managers should be aware of that risk, especially given the national wildfire recurrence history;
- b. the development of risk maps should consider different sources of data for their development in order to account for uncertainties in their predictions, creating thus better decision-making products;
- c. the validation of soil erosion estimations with field data was important to evaluate the robustness of model predictions, compare distinct scenarios and understand which data sources are the most suitable for model application.

The authors believe this modelled map could be of great use for land managers in the post-fire decision-making process in Portugal allowing the early identification of critical areas for the implementation of emergency stabilization measures, and such work should be expanded outside the Portuguese territory.

Declarations

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Author contributions

Parente J. executed the modelling, prepared the figures wrote the main manuscript text. Girona-García A., Lopes A.R., and Keizer J.J defined the article structure, narrative and review. Vieira D.C.S. defined modelling approach, article concept, review and funding.

Competing interests

The author(s) declare no competing interests.

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Figures

Figure 1

Wildfire frequency between 1980-2018 in Portugal according to the National Mapping Burned Area dataset^{57,58}. Points indicate the location of the validation sites defined in Table 2: Montesinho (MONT.), Ermida (ERM.), Pessegueiro do Vouga (PES.), Açores (ACO.), Várzea (VAR.), Semide (SEM.), Colmeal (COL.).

Figure 2

Maps of slope angle of mainland Portugal (left) at a spatial resolution of 25 m²⁹, and of land cover (right) considering the national inventory data from 2018 (COS2018), with a cartographic resolution of 1 ha and a minimum distance between cartographic units of 20 m⁵⁹.

Figure 3

Total precipitation per year in the hydrological period between 1980 and 2018 according to the ERA-Interim (left) and ERA5 (right) datasets.

Figure 4

Predicted soil losses risk classes ($\text{Mg ha}^{-1} \text{ y}^{-1}$) for each burn severity scenario (low, moderate, high) in the year 2001, according to the ERA-Interim (top) and ERA5 (bottom) rainfall datasets.

Figure 5

Maps of the differences between the soil losses ($\text{Mg ha}^{-1} \text{y}^{-1}$) predicted for the year 2001 using the ERA-Interim rainfall data and those predicted using the ERA5 rainfall datasets for three burn severity scenarios (low, moderate, high), according with quintile measures.

Figure 6

Measured and predicted soil losses (Mg ha⁻¹ y⁻¹) for reference soil erosion sites (Table 2) according with ERA-Interim (EI, green bars), ERA5 (E5, blue bars) dataset, and local rainfall (local R, grey bar) measurements.

Figure 7

Differences between measured and predicted soil losses (Mg ha-1 y-1) for reference soil erosion sites (Table 2) according with ERA-Interim (EI, green points), ERA5 (E5, blue points) dataset, and local rainfall (local R, grey bar) measurements.

Post-fire soil erosion risk map for Eucalypt, Pinus and Scrubland areas

Figure 8

Post-fire soil erosion risk map for eucalypt, pine and scrubland areas in mainland Portugal.