1. INTRODUCTION

Soil erosion by water is an unsolved major environmental problem, threatening the sustainability and productive capacity of agriculture but, on the other hand, it is one of the main sources of sediment supply to the coastal zone. Thus, its quantification is also a major issue in the management of coastal occupation and risk. The evaluation of sediment delivery to the coast can be assessed by using several methods [1] among which the Revised Universal Soil Loss Equation (RUSLE) model [2, 3] is the most currently used. Since this method targets the objective quantification of the present or near-present soil loss rate, it is usually applied parameterizing the control variables at an annual to inter-annual time scale. However, in applications where erosion cannot be considered stationary, such as those related with climate change or mesoscale change in land use, it should account for the time-variability of the primary variables. This study contributes to assessing the application of RUSLE in long-term studies. First results of an application of the GIS-based RUSLE model to evaluate potential changes in the intensity of soil erosion in watersheds draining to the central western coast of Portugal (Figure 1) are presented and discussed considering a time window extending from pristine conditions (prior to human intervention) to the end of the 21st century.

2. METHODS

2.1 Study area

The study area corresponds to the ensemble of watersheds directly draining to the coastal area under jurisdiction of ARH do Tejo, I.P. [1] (one Portuguese governmental authority), subtracted of the Tagus drainage basin (Figure 1). It extends for about 2,800 km² and influences 170 km of the central Portuguese coastline.

2.2 Soil erosion model

The choice of an adequate soil erosion model should rely upon a careful balance between 1) the availability of reliable data and 2) the representation of the dominant variables driving the erosion process. In this study the RUSLE model was chosen because it was developed to assess long-term average annual sediment yield in both complex and contrasting basin morphologies and patterns of land uses [4]; furthermore, it accounts and

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discriminates the major variables driving the hydric erosion system and parameterization of variables is supported by numerous studies of which in large number considered the Portuguese case. According to the RUSLE model (Figure 2), soil erosion is computed through the equation:

\[ A = R \times K \times L \times S \times C \times P, \]

where:
- \( A \): average soil loss (ton.ha\(^{-1}\).year\(^{-1}\)),
- \( R \): rainfall-runoff erosivity factor (MJ.mm.ha\(^{-1}\).h\(^{-1}\).year\(^{-1}\)),
- \( K \): soil erodibility factor (ton.h.MJ\(^{-1}\)mm\(^{-1}\)),
- \( L \): slope length factor (dimensionless),
- \( S \): slope steepness factor (dimensionless),
- \( C \): cover-management factor (dimensionless),
- \( P \): conservation practices factor (dimensionless).

In real case studies at the watershed scale, where the original constrains of the equation are not met, some adjustments are required to the computation of the aforementioned variables, provided that the accuracy of the final result is not prejudiced [5].

In the case addressed here, the erosivity factor \( R \) (\( R = 0.28 \times P - 44.2 \) [6]) was parameterized using a relationship with the annual average precipitation at the Lisbon region (\( P \) in mm, 1931 to 1960 series).

The erodibility factor \( K \) was based upon the 1:1,000,000 Soil Map of Portugal (available at http://sniamb.apambiente.pt/webatlas/index.html), which follows the United Nations FAO classification system. The relations of the factor \( K \) values with the FAO classification follow the systematization table in [7]. The cover-management factor \( C \) was based on the 1990, 2000 and 2006 CORINE land cover maps for Portugal [8], at a 1:1,000,000 scale. The relations between \( C \) values and the CORINE land cover level 1 classes follow the systematization proposed in [9]. To make the RUSLE model suitable at the catchment scale the \( L \) and \( S \) factors were merged into a single topographic factor (\( LS \)) following [1, 10]:

\[ LS = \left( \frac{FlowAccuCellSize}{22.13} \right)^{0.4} \times 1.4 \left( \frac{\text{Sin(Slope)}}{0.0896} \right)^{1.3} \]

Finally, in line with other erosion studies, the \( P \) factor was considered equal to 1 due to impossibility of spatial discrimination. The calculations and data integration were made with the ESRI\textsuperscript{®} ArcMap10 GIS software.

This study considers five land use and climatic scenarios of which three represent near present conditions (1990, 2000 and 2006) and 2 modeled scenarios (pristine conditions and the year 2100). To simulate pristine settings a \( C \) factor of 0.0175 (estimated by averaging the 1990 \( C \) values in Forest and semi-natural areas) was also applied to the Agriculture and Artificial areas. The 2100 scenario accounting for land use and climate changes was simulated considering a 50% increase in burnt areas (Sc1) and decreasing mean annual precipitation by 10% (Sc2) in line with [11].

### 3. RESULTS AND DISCUSSION

Results for different time slices are shown in Figure 3 and Table 1, and were segmented in the following five level-1 CORINE land cover classes: water bodies (WB), wetlands (W), agriculture (A) areas, forest and semi-natural (FSN) areas, and artificial (AR) areas. The RUSLE model yielded a net soil loss of 9.7x10\(^5\) ton/year when
parameterized with 1990’s conditions and this was further considered as an arbitrary reference frame in further comparisons.

![Image](image_url)  
**Figure 1.** Study area with watersheds limits.  

![Image](image_url)  
**Figure 2.** Flowchart of the soil erosion map computation.

Cultivated land is the most relevant contributor (81%) to this grand total followed by FSN areas (17%). A first attempt to reconstruct pristine conditions was undertaken extending the FSN classification to the whole watershed excepting WB and W areas. This translated into a significant reduction of the potential soil erosion (~50%). Differences in potential soil erosion between 1990 and 2006 assessed through CORINE land cover changes in land use are smaller than 5%, do not follow a clear trend and are essentially related to the proportion of FSN areas consumed by fire. Projections of future scenarios by the end of the 21st century considered land cover changes in relation to forest fires (+50% in relation to 1990) and modification of average rainfall (-10% in relation to 1990) with opposite effects: the former increases soil erosion by 7%, whereas the latter decreases that value by 13%.

### 4. CONCLUSION

This study presents a first attempt to introduce the temporal dimension in the complex issue of the soil erosion system, combining a GIS-based approach fed with multi-temporal data from several sources and the RUSLE predictive model. Although the results should be considered as preliminary, they clearly show the robustness of the method in ranking the relative importance of the each variable of the erosion system, not only in a predefined time window but also to compare changes between instantaneous pictures separated in time. Our results indicate, as expected, dramatic differences in soil erosion intensity - and thus in sediment delivery - between pristine and human-intervened scenarios although the computed magnitude requires further investigation and validation. Anthropogenic effects translate in a number of different patterns of land use, among which agriculture comes out as the most relevant modulator of soil loss in the study area, overwhelming the effect of both past and projected future changes in the erosivity factor driven by climatic changes at the century time scale.
Figure 3. Soil erosion by watershed in computed scenarios (see text for explanation).

Figure 4. Soil erosion in computed scenarios (see text for explanation).

5. REFERENCES