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SCIENCE

# Soil erosion, Serra de Grândola (Portugal)

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**ABSTRACT**
Soil erosion has long been the subject of attention for environmental management researchers because it implies the loss of a key natural resource for sustaining life. Several methodologies for soil erosion assessment have been developed; many of these are supported by Geographic Information Systems. This study aims to classify the susceptibility of rainfall-induced erosion at the Serra de Grândola (Portugal), based on the Priority Actions Programme/Regional Activity Centre guidelines for mapping soil erosion on the Mediterranean coast. Results show a low-to-moderate susceptibility to rainfall-induced erosion in the lowlands, becoming moderate to high in the highlands of the Serra de Grândola.

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Soil erosion; landsat; DEM; PAP/RAC; NDVI; Serra de Grândola

## 1. Introduction

Erosion is a global threat to sustainability and soil productivity. Understanding the genesis of this process is a central key for environmental management because it allows people to model, quantify and classify the susceptibility of land to soil erosion. In the Iberian Peninsula, soil erosion is the most common process of land degradation and a symptom of desertification (Castillo, 2000), and rainfall-induced erosion is responsible for the degradation of Mediterranean soils (Cerdà, Hooke, Romero-Diaz, Montanarella, & Lavee, 2010; Grimm, Jones, & Montanarella, 2002; Kosmas, Danalatos, & Gerontidis, 2000). Understanding the characteristics and the spatial and temporal variability of rainfall is thus crucial for soil erosion assessment, and for the adoption of sustainable land management strategies minimizing the loss of soil (Nunes & Lourenço, 2015).

The Mediterranean region is characterized by a seasonal climate and the resulting specific ecological and soil conditions. The fragile environment and low biomass production rates during dry periods make it one of the most vulnerable ecosystems in Europe. According to Hanson et al. (2007), projected changes of precipitation in the Mediterranean area caused by climate change suggest higher extreme precipitation events in the future. An increase in susceptibility to soil erosion is also expected (Figueredo & Gonçalves, 2008).

The Priority Actions Programme/Regional Activity Centre (PAP/RAC) was established in 1977 as a main component of the Mediterranean Action Plan (MAP), within the scope of the United Nations Environment Programme (UNEP). The MAP included 21 countries form the Mediterranean as well as the European Union, with the common goal of contributing to a healthier and more sustainable Mediterranean environment. The model proposed by PAP/RAC (1997) to predict rainfall-induced erosion in the Mediterranean coastal areas is simple and versatile, and does not require the use of complex parameters that may be difficult to obtain, such as those needed in the Universal Soil Loss Equation model (Zavala et al., 2005).

Geographic information systems (GIS) can be used for the assessment of natural resources as it allows the integration and representation of several biophysical attributes (e.g. Bastian, 2000; Bocco, Mendoza, & Velázquez, 2001). The incorporation of digital elevation models (DEMs) allows the representation of topographic characteristics and so the simulation of the environmental processes.

This paper presents a GIS-based methodology developed from PAP/RAC (1997) to map the susceptibility of the Serra de Grândola to rainfall-induced erosion. The map coordinate system is the ETRS-1989-Portugal-TM06 (EPSG: 3763). The datum is ETRS89 and the ellipsoid is the GRS80. The Transversal Mercator projection has its origin at the Portuguese geodetic centre (Melriça, Portugal). Susceptibility to erosion is presented as a colour scheme on the map (1:35,000) in which five classes are differentiated (very low, low, moderate, high and very high).

## 2. Study area

The Serra de Grândola is a mountain range in the Alentejo region, South of Portugal (N 38° 0′ to N 38° 13′ and W 8° 32′ to W 8° 44′) (Figure 1). Annual rainfall

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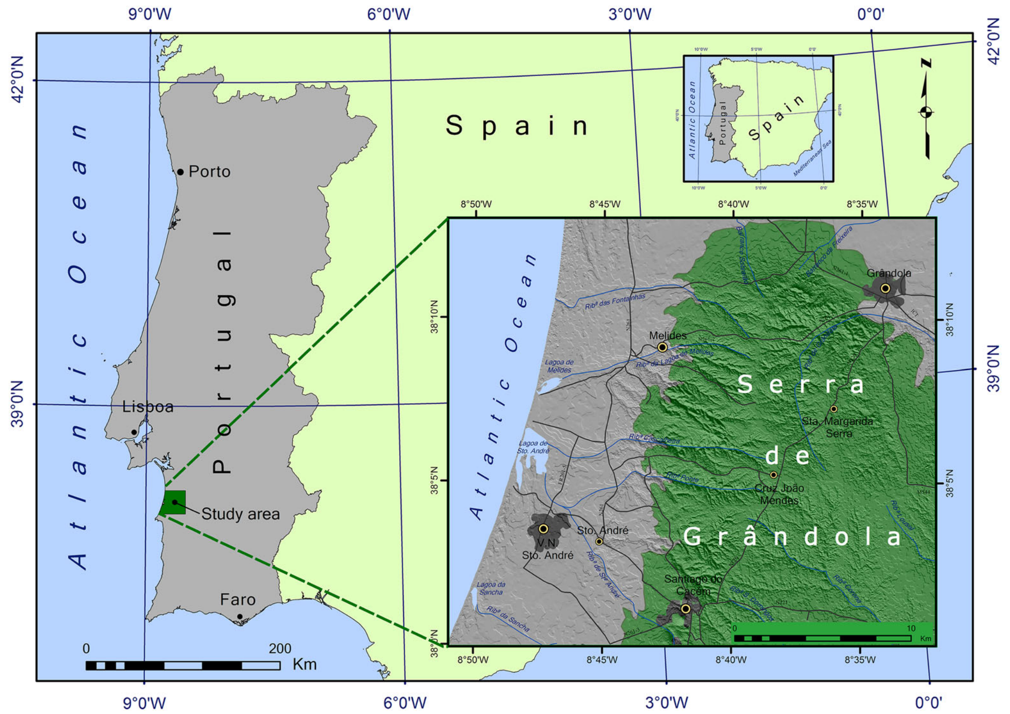


**Figure 1.** Location of the Serra de Grândola, and the study area.

ranges from 600 mm (in the lowlands) to 1050 mm (in the highlands). The climate is moderate, with an average annual temperature of 17°C. The most important lithologic group is the Flysch formation of the lower Alentejo (DGM, 1984).

The Serra de Grândola is noted for its ecologic and landscape value, and for the low-impact natural resource management practices of the local population. The Mediterranean climate produces specific ecological conditions mainly because of the distinctive high-contrast relief with the mountain area surrounded by lowland plains and because of close proximity to the Atlantic Ocean. Temporary ponds are extremely important for some species of amphibians and macroinvertebrates (Pereira, 2011), and dense riparian vegetation provides habitats for various species of birds, and for mammals such as the otter (Lutra Lutra) (Salgueiro, 2009).

## 3. Methods

Assessment of the susceptibility of the Serra de Grândola to rainfall-induced erosion is based on a GIS method that integrates the physical and meteorological driving properties (vegetation cover, relief, soil use, lithology and rainfall). The methodology follows Paixão (2012), who combined the impact of the mechanical action of rainfall (erosivity) with the susceptibility to soil erosion (erosion status) in order to map the susceptibility of the Serra de Grândola to rainfall-induced erosion (Figure 2).

The rainfall erosivity map was produced from the Modified Fournier Index (MFI) (Arnoldus, 1978) and classified according to CORINE-CEC (1992). Erosion status mapping is based on the guidelines for mapping and measurement of rainfall-induced erosion processes in Mediterranean coastal areas (PAP/RAC, 1997), with regional specifications for the Southern Iberian Peninsula as suggested by Jordán and Bellinfante (2000), Zavala (2001), Zavala, Bellinfante, Jordán, and Paneque (2002, 2005) and Jordán, Zavala, Bellinfante, and González (2005).

### 3.1. Erodibility map

The erodibility map was generated by combining the slope and lithofacies maps. The slope map was produced from a 10-m resolution DEM (Supplementary Figure 1) using 526,770 points digitized from contours of a 1:25,000 topographic map (Geographical Institute of the Portuguese Army; IGeoE, 2004). Elevations were interpolated using ordinary kriging, in which the variogram was modelled from a spherical model.

Slopes were calculated from the elevation differences of the adjacent cells, for each cell of the DEM. The slope of each pixel in line $l$ and column $k$ is find based on the elevation values ($H$) of neighbouring pixels and on the spatial resolution of the DEM, $E$. The slope is calculated using the following equation:

$$\delta = \sqrt{\left(\frac{H(l,k+1)-H(l,k-1)}{2E}\right)^2 + \left(\frac{H(l-1,k)-H(l+1,k)}{2E}\right)^2}. \quad (1)$$

Five classes of slopes (%) were derived from the DEM: [0, 3[, [3, 16[, [16, 21[, [21, 31[ and ≥31 (Supplementary Figure 2).

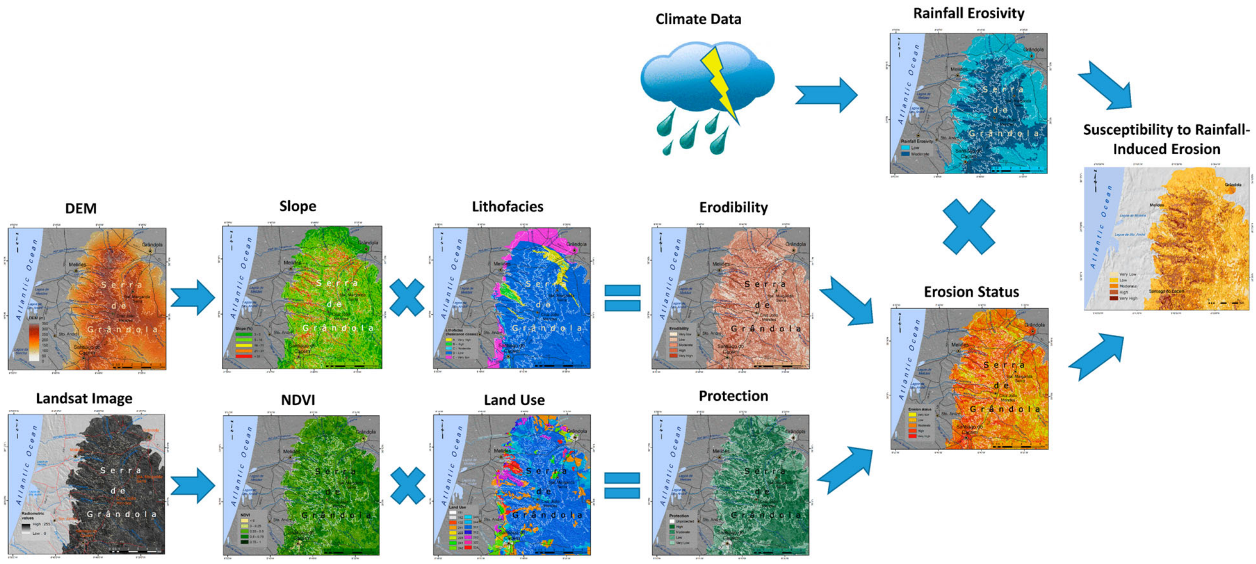


**Figure 2.** Methodology used to assess the susceptibility to rainfall-induced erosion.

The lithofacies map (Supplementary Figure 3) was produced from the 1:200,000 Geological Map of Portugal (DGM, 1984) by aggregating lithological units with similar characteristics with the material resistance. Five classes of lithofacies were defined: A – very high, B – high, C – moderate; D – low and E – very low. Slope was combined with lithofacies according to Supplementary Table 1 to generate the erodibility map (Supplementary Figure 4). The outcome was five classes of erodibility: a – very low; b – low; c – moderate; d – high and e – very high.

### 3.2. Soil protection map

Red and near-infrared bands of Landsat 8 OLI scenes (WRS path: 203; WRS row: 34; file date: 2013/08/16) were used to calculate the Normalized Difference Vegetation Index (NDVI) (Rouse, Hass, Schell, & Deering, 1974), which was then used to produce the vegetation cover map. Four classes of vegetation cover (%) were mapped: [0, 25[, [25, 50[, [50, 75[ and [75, 100] (Supplementary Figure 5).

Land use data were obtained from the Corine Land Cover map (CLC, 2006) by merging classes with similar characteristics (Supplementary Figure 6).

Vegetation cover was combined with soil use (see Supplementary Table 2) to produce the soil protection map (Supplementary Figure 7). The outcome was five levels of soil protection: a – unprotected, b – very low, c – low, d – moderate and e – high.

### 3.3. Erosion status map

Erodibility was combined with soil protection (see Table 1) to produce the erosion status map (Supplementary Figure 8). The resulting erosion status values were categorized into: 1 – very low, 2 – low 3 – moderate 4 – high and 5 – very high.

**Table 1.** Five classes of erosion status (calculated from erodibility and soil protection) were defined: 1 –very low, 2 – low 3 –moderate 4 –high and 5 –very high.

| | Erodibility class | | | | |
|---|---|---|---|---|---|
| Soil protection class | a | b | c | d | e |
| A | 1 | 1 | 1 | 2 | 2 |
| B | 1 | 1 | 2 | 3 | 4 |
| C | 1 | 2 | 3 | 4 | 4 |
| D | 2 | 3 | 3 | 5 | 5 |
| E | 2 | 3 | 4 | 5 | 5 |
| Unprotected | 3 | 4 | 5 | 5 | 5 |

**Table 2.** Five classes of rainfall erosivity (Corine – CEC) using the MFI.

| Rainfall erosivity class | MFI | Rainfall agressivity |
|---|---|---|
| 1 | <60 | Very low |
| 2 | 60–90 | Low |
| 3 | 90–120 | Moderate |
| 4 | 120–160 | High |
| 5 | >160 | Very high |

**Table 3.** Five classes of susceptibility to rainfall-induced erosion calculated from erosion status and rainfall erosivity were defined: I –very low, II –low, III –moderate, IV –high and V – very high.

| | Rainfall erosivity class (CORINE – CEC) | | | | |
|---|---|---|---|---|---|
| Erosion status class | 1 | 2 | 3 | 4 | 5 |
| 1 | I | I | I | II | III |
| 2 | I | II | II | III | IV |
| 3 | I | II | III | IV | V |
| 4 | II | III | IV | IV | V |
| 5 | III | IV | V | V | V |

### 3.4. Rainfall erosivity map

Rainfall erosivity is a parameter of major importance for soil erosion assessment purposes. However, often there is a lack of rainfall data for the area under study. In the Serra de Grândola, there is only one climatological station (Grândola 24F/01C, Portuguese

**Table 4.** Susceptibility to rainfall-induced erosion in the Serra de Grândola. Area, slope, type of lithofacies, land cover and rainfall erosivity are listed for each class of susceptibility to rainfall-induced erosion.

| Susceptibility to erosion | Area ($km^2$) | Slope (%) | Lithofacies | Land cover | Rainfall erosivity |
|---|---|---|---|---|---|
| Very low | 45.9 | 0–3 | Schits, phyllites, silltites, quartzites and formation of Mira | Forest | Low |
| Low | 151.9 | 0–16 | Formation of Mira and Mértola | | |
| Moderate | 100.6 | 3–16 | | | Moderate |
| High | 41.1 | 16–31 | | Forest/non-irrigated arable land | |
| Very high | 5.1 | >21 | | | |

Ministry for Agriculture, Sea, Environment and Land Planning). To overcome this issue, a model for annual precipitation using multi-linear regression was developed (for further details of this model, see Paixão, 2012). Input data were the monthly average rainfall for the period from 1 January 1911 to 31 December 2010, not only from station 24F/01C but also from 28 climatologic stations closest to the Serra de Grândola (all stations within the same drainage basin). Rainfall erosivity was classified according to CORINE-CEC (1992) (Table 2) (Supplementary Figure 9).

### 3.4. Susceptibility to rainfall-induced erosion map

Erosion status was combined with rainfall erosivity (see Table 3) to produce the susceptibility to rainfall-induced erosion map (see Main Map). The outcome was five classes of susceptibility to water erosion: I – very low, II – low, III – moderate, IV – high and V – very high. The susceptibility to erosion map was classified according to slope, lithofacies, soil coverage and rainfall erosivity (Table 4).

## 4. Conclusions

Environmental biophysics requires knowledge about the resources and processes affecting ecological system conservation, as well as about planning and land management.

The integration of GIS with DEMs allows good representation of topographic characteristics and easy simulation of the environmental processes. This paper presents a methodology based on GIS tools for mapping and classifying the susceptibility to rainfall-induced erosion in the Serra de Grândola (Portugal). A DEM is used as the starting point for the automatic classification, which is based on the Priority Actions Programme/Regional Activity Centre (PAP/RAC) procedures, with regional specifications for the Southern Iberian Peninsula. The data sets used for computation included slope, lithofacies, NDVI and land use. The integration in a GIS was an important tool for simulating erodibility and soil protection, to produce the erosive state information and to combine it with rainfall data. PAP/RAC proved to be a useful set of guidelines for predicting rainfall-induced erosion in the Serra de Grândola.

The Corine-CEC classification shows the study area as having low- and moderate-rainfall erosivity. Lower rainfall erosivity values correspond to the surroundings of the central part of the mountain range, which shows moderate MFI values. It was found that the study area has a low-to-moderate susceptibility to rainfall-induced soil erosion. The highlands are more susceptible because of the higher amount of rainfall and steeper slopes, although the soil material is more resistant to erosion (flysh formation). Valleys with steep hillslopes presented a very high susceptibility to rainfall-induced erosion (e.g. Ribª da Lagoa de Melides, Ribª Cascalheira, Ribª Ponte and Ribª de Stº André).

The authors hope that this work may contribute to better planning of land use at the Serra de Grândola, which is particularly sensitive to the erosive process due to its ecological and landscape qualities.

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## Disclosure statement

No potential conflict of interest was reported by the authors.

## Software

IDRISI Taiga was used as the analysis platform for modelling the susceptibility to water erosion. Esri ArcGIS 10.2 was also used to design the maps.

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