A pan-European quantitative assessment of soil loss by wind

Borrelli P, Lugato E, Montanarella L, Panagos P
Wind erosion creates many problems on Europe. In **northern Europe** the problem is severe on light sandy soils (...). Wind erosion also occurs on more silt- or clay-rich soils in the drier parts of **southern Europe**, but the problem is less well researched, and probably less extensive or intense.

*Source: Wind erosion on agricultural land in Europe. Andrew Warren, 2002*
In 2013, the European Commission requested to the JRC a new wind erosion assessment.

LUCAS topsoil sampling

Wind-erodible fraction of soil

Index of Land Susceptibility to Wind Erosion

Borrelli et al., 2014. Geoderma, 232

Borrelli et al., 2014. Land Degradation & Development (in press)

Borrelli et al., 2015. Sustainability, 7
In 2013, the European Commission requested to the JRC a new wind erosion assessment

The average annual soil loss predicted by GIS-RWEQ in the EU arable land totalled 0.53 Mg ha\(^{-1}\) yr\(^{-1}\), with the 2\(^{nd}\) quantile and the 4\(^{th}\) quantile equal to 0.3 and 1.9 Mg ha\(^{-1}\) yr\(^{-1}\), respectively.
THANK YOU FOR YOUR ATTENTION

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Research on wind erosion: Step 1 – Soil erodibility

**APPROACH OVERVIEW**

To gain a better understanding of the geographical distribution of wind erosion processes in Europe, we propose an integrated mapping approach to estimate soil susceptibility to wind erosion. The wind-erodible fraction of soil (EF) is one of the key parameters for estimating the susceptibility of soil to wind erosion. It was computed for 18,730 geo-referenced topsoil samples (from the Land Use/Land Cover Area frame statistical Survey (LUCAS) dataset). Our predication of the spatial distribution of the EF and a soil surface crust index drew on a series of related but independent covariates, using a digital soil mapping approach (Cubist-rule-based model to calculate the regression, and Multilevel B-Splines to spatially interpolate the Cubist residuals).

The digital soil mapping approach was employed to calculate the wind-erodible fraction of soil and soil surface crusting factor by deriving its distribution from a series of related but independent covariates (Goovaerts, 1998). This approach aims to establish a statistical relationship between the property to be calculated and a set of spatially exhaustive covariates. Once this relationship is found, the dependent property is estimated everywhere within the geographic frame of interest.

The value of the wind-erodible fraction of soil and soil surface crusting factor that were calculated for the LUCAS points were interpolated using a series of environmental descriptors (covariates), in order to map its spatial distribution. Regression residuals were then spatially interpolated according to their covariance function. In general, this kind of model can be described as:

\[
\hat{z}(s_0) = \hat{\mu}(s_0) + \hat{\epsilon}(s_0)
\]

where \(\hat{\mu}(s_0)\) represents the deterministic part fitted by the regression model and \(\hat{\epsilon}(s_0)\) represents the interpolated residuals.

The two components were then summed to obtain the final estimation of the erodible fraction. This hybrid approach was performed using the Cubist-rule-based model (Quinlan, 1992) to carry out the regression, and Multilevel B-Splines (MBS; Lee et al., 1997) to spatially interpolate the Cubist residuals.

The twenty most important covariates and their relative importance in the application of Cubist/MBS model for wind-erodible fraction of soil (EF) prediction. (i) Latitude; (ii) altitude above channel network; (iii) elevation; (iv) PCAb1 of Red band; (v) PCAb3 of NIR band; (vi) PCAb1 MIR; (vii) PCAb3 MIR; (viii) MIR; (ix) PCAb1 EVI; (x) PCAb5 MIR; (xi) drainage network; (xii) land use and land cover; (xiii) PCAb2 NIR; (xiv) longitude; (xv) multi resolution valley bottom flatness index; (xvi) slope gradient; (xvii) PCAb2 Red; (xviii) NIR; (xix) PCAb4 MIR; and (xx) PCAb2 MIR.

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Research on wind erosion: Step 1 – Soil erodibility

Map of the soil crust factor of European soils (500 m spatial resolution)

The average wind-erodible fraction of soil (EF), according to European Union NUTS-3 administrative units

Map of wind erosion susceptibility of European soils (500 m spatial resolution)
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Research on wind erosion: Step 1 – Soil erodibility

**APPROACH OVERVIEW**

The spatial interpolation showed a good performance with an overall R2 of 0.89 (in fitting). We observed the spatial patterns of the soils’ susceptibility to wind erosion, in line with the state of the art in the literature. We used regional observations in Lower Saxony and Hungary to ensure the applicability of our approach. These regional control areas showed encouraging results, and indicated that the proposed map may be suitable for national and regional investigations of spatial variability and analyses of soil susceptibility to wind erosion.

**RESULTS**

We estimated the wind-erodible fraction based on the 15.786 million cells (500 m spatial resolution) into which we subdivided the surface of the 25 EU countries (Table). The resulting erodible fraction values ranged from 3.6% to 69.0%, with a mean value of 30% (± 10.6%). According to the erodibility classification proposed by Shiaytii (1965), which has been adopted for European contexts by López et al. (2007), 81.3% (EF ≤ 40%) and 13.8% (EF ≥ 40% and ≤ 50%) of the investigated area are characterised by slight and moderate erodibility, respectively, whereas 4.9% are characterised by high erodibility (EF > 50%).

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean [%]</th>
<th>Maximum</th>
<th>Standard deviation</th>
<th>Coefficient of variation</th>
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**Figure.** Comparison of the predicted wind erosion susceptibility of soil (background raster image) with regional observations (represented with yellowish lines). a) The Geest area in Lower Saxony. This area mainly consists of glacial moraines and sand plains, forming light sandy soils largely endangered by wind erosion (Capelle, 1990; Gross and Schäfer, 2004, among others). b) Area affected by wind erosion in Hungary according to Stefanovits and Várályi (1992).

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Research on wind erosion: Step 2 – Land susceptibility to wind erosion

**Approach Overview**
Understanding spatial and temporal patterns in land susceptibility to wind erosion is essential to design effective management strategies to control land degradation. The knowledge about the land surface susceptible to wind erosion in European contexts shows significant gaps. The lack of researches, particularly at the landscape to regional scales, prevents national and European institutions from taking actions aimed at an effective mitigating of land degradation. This study provides a preliminary pan-European assessment that delineates the spatial patterns of land susceptibility to wind erosion and lays the groundwork for future modelling activities. An Index of Land Susceptibility to Wind Erosion (ILSWE) was created by combining spatiotemporal variations of the most influential wind erosion factors (i.e. climatic erosivity, soil erodibility, vegetation cover and landscape roughness). The sensitivity of each input factor was ranked according to fuzzy logic techniques. State-of-the-art findings within the literature on soil erodibility and land susceptibility were used to evaluate the outcomes of the proposed modelling activity.

**Study Area**
The study area includes the lands of the 28 Member States of the European Union (EU-28), three European Union candidate countries (i.e. Montenegro, Serbia, the Former Yugoslav Republic of Macedonia), three potential European Union candidate countries (i.e. Albania, Bosnia and Herzegovina, and Kosovo), Norway and Switzerland (Figure 1).

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Research on wind erosion: Step 2 – Land susceptibility to wind erosion

Number of erosive days. A) Spatial distribution of potentially erosive days (wind-speed threshold assumed as 7 ms\(^{-1}\)); B) spatial distribution of erosive days corrected according the proposed topsoil moisture content.

A) Map of wind-erosion susceptibility of European soils (500m spatial resolution) based on the estimation of the wind-erodible fraction of soil (EF) (Chepil, 1941; Fryrear et al., 2000); B) average annual percentage of soil surface covered by vegetation derived by LAI and FSoil indices; C) landscape roughness length (z0 in m) in Europe derived from CORINE and land cover classification using TA–LUFT parameters (2001).

Index of Land Susceptibility to Wind Erosion (ILSWE) predicted for 36 European countries (spatial resolution 500 m).

Borrelli et al., 2014. Land Degradation & Development (in press)
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Research on wind erosion: Step 3 – Quantitative soil loss (GIS-RWEQ)

**Approach Overview**
Field measurements and observations have shown that wind erosion is a threat for numerous arable lands in the European Union (EU). Wind erosion affects both the semi-arid areas of the Mediterranean region as well as the temperate climate areas of the northern European countries. Yet, there is still a lack of knowledge which limits the understanding about where, when and how heavily wind erosion is affecting European arable lands. Currently, the challenge is to integrate the insights gained by recent pan-European assessments, local measurements, observations and field-scale model exercises into a new generation of regional-scale wind erosion models. This is an important step to make the complex matter of wind erosion dynamics more tangible for decision-makers and to support further research on a field-scale level.

A GIS version of the Revised Wind Erosion Equation (RWEQ) was developed to i) move a step forward into the large-scale wind erosion modelling, ii) evaluate the soil loss potential due to wind erosion in the arable land of the EU, and iii) provide a tool useful to support field-based observations of wind erosion.

**Results**
The model was designed to predict the daily soil loss potential at a ca. 1 km² spatial resolution. The average annual soil loss predicted by GIS-RWEQ in the EU arable land totalled 0.53 Mg ha⁻¹ yr⁻¹, with the 2nd quantile and the 4th quantile equal to 0.3 and 1.9 Mg ha⁻¹ yr⁻¹, respectively. The cross-validation shows a high consistency with local measurements reported in literature.