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Wind erosion susceptibility of European soils

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ABSTRACT

The EU Thematic Strategy for Soil Protection identified soil degradation caused by erosion as one of the major threats to European soils. A thorough literature review revealed important gaps in research on soil erosion processes in Europe. This is particularly true for wind erosion processes. The current state of the art in erosion research lacks knowledge about where and when wind erosion occurs in Europe, and the intensity of erosion that poses a threat to agricultural productivity. 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 spatial interpolation showed a good performance with an overall R^2 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.

1. Introduction

Wind erosion is a widespread phenomenon causing serious soil degradation in arid and semi-arid regions (FAO, 1960; Wolfe and Nickling, 1993). In its more severe forms it can constitutes a threat to cropping and contributes to the degradation of a sustainable cropping agriculture (Lyles, 1975). The wind induced movement of soil occurs when three environmental conditions coincide: i) the wind is strong enough to mobilize soil particles, ii) the characteristics of the soil make it susceptible to wind erosion (soil texture, organic matter and moisture content) and iii) the surface is mostly devoid of vegetation, stones or snow (Bagnold, 1941; Nordstrom and Hotta, 2004; Shao, 2008).

Wind erosion has always occurred as a natural land-forming process (Livingstone and Warren, 1996) but, today, the geomorphic effects of wind are locally accelerated by anthropogenic pressures (e.g. leaving cultivated lands fallow for extended periods of time, overgrazing rangeland pastures and, to a lesser extent, over-harvesting vegetation (Leys, 1999)).

Land degradation due to wind erosion is also an European phenomenon (Warren, 2003) which locally affects the semi-arid areas of the Mediterranean region (Gomes et al., 2003; Lopez et al., 1998; Moreno Brotons et al., 2009) as well as the temperate climate areas of the northern European countries (Bärring et al., 2003; De Ploey, 1986; Eppink and Spaan, 1989; Goossens et al., 2001). According to the EU Thematic Strategy for Soil Protection (European Commission, 2006), an estimated 42 million hectares are affected by wind erosion in Europe. However, the latest investigations within the framework of EU projects (Wind Erosion on European Light Soils (WEELS)) and Wind Erosion and Loss of Soil Nutrients in Semi-Arid Spain (WELSONS; Warren, 2003) suggest that the areas potentially affected by wind erosion may be more widespread than previously reported by the European Environment Agency (EEA, 1998). Field observations and measurements found that the areas that the European Environment Agency reported as being only slightly affected by wind erosion (EEA, 1998) have actually undergone severe erosion (Böhner et al., 2003; Riksen and De Graaff, 2001). These field research findings reveal that the European Environment Agency (EEA, 1998) currently has an incomplete picture about the occurrence and scope of wind erosion in Europe. This could lead to incorrect decision making by national and European institutions in seeking to mitigate wind erosion. To fulfil the goal of the EU Thematic Strategy for Soil Protection (European Commission, 2006), research must aim to better understand where and under which conditions land degradation by wind erosion is most likely to occur. The methodologies that are applied must be harmonised in order to effectively locate the wind erodible areas in Europe.

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Table 1
List of environmental covariates used for the spatial interpolation.

Parameter	Data source	Spatial resolution
Land use and land cover data	International Geosphere–Biosphere Programme	1 km
Monthly temperatures (min & max)	WorldClim — Global Climate Data v 1.4	1 km
Monthly precipitations	WorldClim — Global Climate Data v 1.4	1 km
Satellite imagery		
Red, blue, green, near infrared (NIR) and middle infrared (MIF) bands	NASA — Moderate Resolution Imaging Spectroradiometer (MODIS)	250 m
Principal Component Analysis of the satellite imagery	NASA — Moderate Resolution Imaging Spectroradiometer (MODIS)	250 m
Vegetation indices: Enhanced Vegetation Index (EVI) & Normalized Differenced Vegetation Index (NDVI)	NASA — Moderate Resolution Imaging Spectroradiometer (MODIS)	250 m
Principal Component Analysis of the Enhanced Vegetation Index & Normalized Differenced Vegetation Index	NASA — Moderate Resolution Imaging Spectroradiometer (MODIS)	250 m
Digital Elevation Model (DEM)	NASA SRTM Digital Elevation Database v4	90 m
Multi-resolution valley bottom flatness index	DEM derivative	90 m
Slope gradient	DEM derivative	90 m
Drainage network	DEM derivative	90 m
Altitude above channel network	DEM derivative	90 m
Down-slope distance	DEM derivative	90 m
Latitude & latitude	Coordinate system (ETRS_1989_LAEA)	–

This study provided an assessment of the susceptibility of European soils to wind erosion. It is a key parameter of integrated modelling for the spatial assessment of the wind erosion risk (Hagen, 2004). The erodibility of European soil was estimated as the wind-erodible fraction, a simplification of Chepil's (1941) work (Woodruff and Siddoway, 1965). Soil characteristics were obtained from the first topsoil survey of the whole European Union (Tóth et al., 2013). The assessment presented in this paper is part of a preliminary investigation that aims to further investigate the patterns of soil susceptibility to wind erosion across Europe, and to research the occurrence of wind erosion at regional and European scales.

2. Material and methods

2.1. Study area

The study area was made up of 25 member states of the European Union. Bulgaria, Romania and Croatia were excluded from the study because data from their LUCAS soil samples were not available. The total land surface is about 4 million km^2, providing living space for a population of about 470 million (Eurostat, 2012). According to Eurostat (2012) two-fifths (about 1.55 million km^2) of the total land area was used for agricultural purposes in 2007.

2.2. Soil database

Soil information for the 25 EU member states was acquired from the Land Use/Land Cover Area frame statistical Survey (LUCAS) database, which provided data from 2009 onwards. This was combined with a topsoil assessment component ('LUCAS-Topsoil' — Tóth et al., 2013). LUCAS-Topsoil comprises the first harmonised and comparable dataset on soil at the European level. We used a merged database that contained 19,967 geo-referenced samples (each of 0.5 kg of topsoil, collected at a depth of 0–20 cm), which was selected from a subset of 200,000 potential LUCAS sampling sites. Budgetary constraints did not allow for a broader sampling exercise. Geostatistical techniques were employed to sample representative points (Tóth et al., 2013). All 19,967 samples were analysed for their coarse fragment percentage, particle size distribution (% clay, silt and sand content), pH value (in $CaCl_2$ and H_2O), organic carbon content (g kg^{-1}), carbonate content (g kg^{-1}), phosphorous content (mg kg^{-1}), total nitrogen content (g kg^{-1}), extractable potassium content (mg kg^{-1}), cation exchange capacity (cmol + kg^{-1}) and multispectral properties.

2.3. Computation of the erodible fraction (EF)

In the early 1950s, the combination of soil sieving and wind tunnel experiments provided evidence of the relationship between soil loss by wind and the characteristics of the soil surface (Chepil, 1950; Chepil and Woodruff, 1954). The field observations revealed that aggregates that were larger than 0.84 mm in diameter were non-erodible under test conditions. As a result of these findings, the proportion of topsoil aggregates < 0.84 mm in diameter (i.e. the wind-erodible fraction (EF) of the soil) became a commonly accepted and widely applied measure of soil erodibility by wind (Colazo and Buschiazzo, 2010; Hevia et al., 2007; Woodruff and Siddoway, 1965), which has been widely employed ever since in prediction models (Chepil et al., 1962; Woodruff and Siddoway, 1965). Fryrear et al. (1994) developed a multiple regression equation for computing the erodible fraction of soils based on the soil's texture and chemical properties (Fryrear et al., 2000):

$$EF = \frac{29.09 + 0.31S_a + 0.17S_i + 0.33S_c - 2.59OM - 0.95CaCO_3}{100} \quad (1)$$

where all variables are expressed as a percentage. S_a is the soil sand content, S_i is the soil silt content, S_c is the ratio of sand to clay