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Condition of agricultural soil: Factsheet on soil erosion

Overview of models, data and information on soil erosion in agricultural soils

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Title Condition of agricultural soil: data on water and wind erosion

Abstract
This report presents a modelling framework to develop indicators on soil erosion. The main focus is the soil erosion estimates in agricultural lands in the view of current monitoring and evaluation of the Common Agricultural Policy (CAP). The factsheet of soil erosion indicator is an example of providing concise information (tables, maps) to policy makers. Besides the current status of soil erosion in agricultural soils, it is also important to estimate trends and provide options to reduce soil erosion. Besides an overview of soil erosion by water, the report presents the estimates of soil erosion by wind.

Contents

Foreword

This document describes the DG AGRI indicator and fact sheet on soil erosion (by water and wind). It consists of an overview of recent data, complemented by definitions, all information on measurement methods and the context needed to interpret them correctly.

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Executive summary

It takes 100 years to form a single centimetre of new soil under natural temperate grasslands. More than 99% of the world's food supply comes ultimately from land-based production depending on soils and this should be considered carefully taking into account the population increase to 9 billion given the threat of climate change. The condition of agricultural soil and its productivity is an important asset to be protected for future generations. Therefore, it becomes important to assess the current threats to soils, in particular, to estimate soil losses by developing biophysical models and developing indicators for monitoring the current status of soil. The loss of soil by water erosion is recognized as main threat for soil degradation both in Europe and globally. In this context, a better understanding of land management dynamics (past, present and future) and their effects on soil erosion is important to help policy makers to protect soil condition and to ensure food security.

Policy context

The monitoring, implementation and evaluation of the Common Agricultural Policy (CAP) 2014-2020 defines a set of 45 Environmental, Socio-Economic and Sectoral indicators known as "CAP Context Indicators". The indicators monitor the general contextual trends that are likely to have an influence on the implementation, achievements and performance of the CAP 2014-2020.

The list of the CAP context indicators is referred to in the COMMISSION IMPLEMENTING REGULATION (EU) No 834/2014 of 22 July 2014 which lays down rules for the application of the common monitoring and evaluation framework of the common agricultural policy and specified in COMMISSION IMPLEMENTING REGULATION (EU) No 808/2014 of 17 July 2014 laying down rules for the application of Regulation (EU) No 1305/2013 of the European Parliament and of the Council on support for rural development by the European Agricultural Fund for Rural Development (EAFRD). For each indicator, a factsheet is compiled containing definitions, a description of the methodology used and data sources.

The Joint Research Centre (JRC), Land Resource Unit (AGSOL workpackage) provides the data, documentation and analysis for the soil erosion by water (C.42) CAP context indicator.

From the soil erosion map of European Union (Panagos et al., 2015), the JRC compiles a range of soil erosion indicator needed to support the:

- European Commission *COM(2006) 508 Communication on Development of Agri-Environmental Indicators for monitoring the integration of Environmental concerns into the Common Agricultural Policy,* Brussels, 2006
- European Commission, *Europe 2020 — A strategy for smart, sustainable and inclusive growth, COM (2010)2020 final*, Brussels, 2010
- Roadmap to a Resource Efficient Europe (COM(2011) 571).
- Sustainable Development Goals (SDGs): *European Commission, Next steps for a sustainable European future: European action for sustainability, COM(2016) 739*, Brussels, 2016.
- Organisation for Economic Co-operation and Development (OECD) Agro-Environmental Indicators

Key conclusions

Every year 2.4 tonnes of valuable topsoil per hectare are lost due to water erosion in the EU-28.

The application of agricultural management practices such as reduced tillage, crop residues, cover crops, grass margins, terraces and contour farming, has reduced soil erosion by 9% in EU-28 during the period 2000-2012.

Soil erosion rates are higher, by a factor of 1.6, compared to soil formation rates.

About 6.7% of the total agricultural lands in EU-28 is suffering from severe erosion (i.e. > 11 $t\ ha^{-1}\ yr^{-1}$).

Water erosion is a more significant threat compared to wind erosion.

This assessment does not consider gully erosion nor erosion due to tillage, which can be locally significant in their own right.

Main findings

According to recent studies, approximately 11.4% of the European Union (EU) territory is estimated to be affected by a moderate to high level soil erosion (more than 5 tonnes per hectare per year). This estimate is slightly lower than previous estimations (in early 2000s) that 16% of EU's land area is affected by soil erosion.

This reduced rate is mainly due to the application of management practices to combat soil erosion which have been applied in Member States during the past decade. About 0.4% of EU land suffers from extreme erosion (more than 50 tonnes per hectare per year).

Mean rates of soil erosion by water in the EU amounted to 2.4 tonnes per hectare per year. The total annual soil loss by water is estimated to 970 million tonnes . This would result in a one metre-depth loss of soil from an area corresponding to the size of the city of Berlin, or a one centimetre loss from an area twice the size of Belgium.

Wind erosion is estimated to be considerably less than water erosion as the mean rate of soil loss by wind in the EU amounted to 0.53 tonnes per hectare per year only in arable lands. The total annual soil loss by wind is estimated to 53million tonnes.

Related and future JRC work

The Land Resources Management Unit of the JRC's Sustainable Reources Directrorate has developed the Agro-Environmental Indicator on soil erosion by water currently available in DG ESTAT:

http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion

The JRC has also contributed to EU Sustainable Development Goals (SDGs) and in specific to the SDG 15 'Life on Land' with the Indicator 'Estimated soil erosion by water':

http://ec.europa.eu/eurostat/web/sdi/life-on-land

The JRC is currently involved in the development of the global soil erosion map (Borrelli, Robinson, Lugato, Ballabio, Montanarella, Panagos et al., Nature Communications, 2017). This unprecedented work shows the impact of land use change on soil erosion with specific focus in agriculture. The results of this study will contribute to the UNCCD research to reach a Global Land Degradation neutrality by 2030.

The JRC plans to estimate the impact on soil erosion of various land use change and policy scenarios.

Quick guide

In this report, we briefly present the current policy framework for developing an indicator on soil erosion and the definition of the indicator 'soil erosion by water'. The model description is a technical part of the document drafting the main data inputs and how they have been compiled in a biophysical model. The results are shown as high resolution soil erosion maps of European Union, factsheets on soil erosion indicator and aggregated statistics on different levels (countries, regions, provinces) plus temporal trends of the indicator. We also present the wind erosion model and estimates which can be supportive information in the main soil erosion indicator.

1 Introduction

Soil erosion by water is one of the major threats to soils in the European Union, which has a negative impact on ecosystem services, crop production, drinking water quality, flood regulation and carbon stocks. The European Commission's Soil Thematic Strategy identified soil erosion as a relevant issue for the European Union and proposed an approach to monitor it.

The land degradation process due to the rate of soil loss exceeding that of soil formation has helped shape today's physical landscape. Soil erosion by water accounts for the greatest loss of soil in Europe compared to other erosion processes (e.g. wind erosion). Recent policy developments in the European Commission (the Soil Thematic Strategy, the Common Agricultural Policy, Europe 2020, and the 7th Environmental Action Programme) call for quantitative assessments of soil loss rates at the European level.

Besides the policy requests, a continental assessment of soil loss may help to: (a) quantify the impacts of soil loss at such a large scale, (b) assess the main effects of climate, vegetation and land use changes on soil erosion rates, and (c) prioritise effective remediation programmes.

The Joint Research Centre has responded to the policy requests by developing a high resolution map of soil erosion by water. Compared to past efforts to develop a similar continental scale map, this new soil erosion map aimed to:

a) Use the most updated input layers of precipitation and rainfall intensity, soil, topography, land use and management;

b) Help predict the effects of land use, climate and policy scenarios;

c) Be replicable, comparable and utilised at a broader scale (other than soil erosion modelling).

The current document presents the soil erosion indicator for assessing the status of agricultural soil in European Union. The soil erosion indicator is updated regularly (3-5 years) and allows comparability between different periods. As topography and soil characteristics remain stable over time, the changing factors are rainfall intensity, vegetation coverage and land management by farmers. The main objective of this study is to present the:

a) Indicator soil erosion by water;

b) Change over time due to management practices and land cover change;

c) Wind erosion estimates.

2 Soil Erosion Indicator definitions

This indicator consists of two sub-indicators:

a) Estimated rate of soil loss by water erosion (t ha^{-1} yr^{-1});

b) Estimated agricultural area affected by a certain rate of soil erosion by water (ha). The estimated area is also expressed as share of the total agricultural area (%).

The indicators assess the soil loss by water erosion processes (rain splash, sheetwash and rills) and give indications of the areas affected by a certain rate of soil erosion (moderate to severe, i.e. >11 t^{-1} ha^{-1} year in the OECD definition). The two soil erosion sub-indicators are based on the output of an enhanced version of the empirical Revised Universal Soil Loss Equation model (named RUSLE2015) (JRC-Ispra) which was developed to evaluate soil erosion by water at a regional scale.

Only soil erosion resulting from rain splash, overland flow (also known as sheetwash) and rill formation are considered. These are some of the most effective processes to detach and remove soil by water. In most situations, erosion by concentrated flow is the main agent of erosion by water.

The results of the soil erosion indicators have been aggregated at NUTS-1[1], NUTS-2 and NUTS-3 levels. The rates of soil loss by water erosion (t ha^{-1} $year^{-1}$) at Member State level represent national average values and therefore may mask higher erosion rates in many areas even for those countries that have a low mean.

The total area of agricultural land has been defined on the basis of Corine Land Cover (CLC) 2012 classes and includes the area of arable and permanent crops, pastures and permanent grasslands.

[1] Nomenclature of Territorial Units for Statistics (NUTS)

3 Model Description

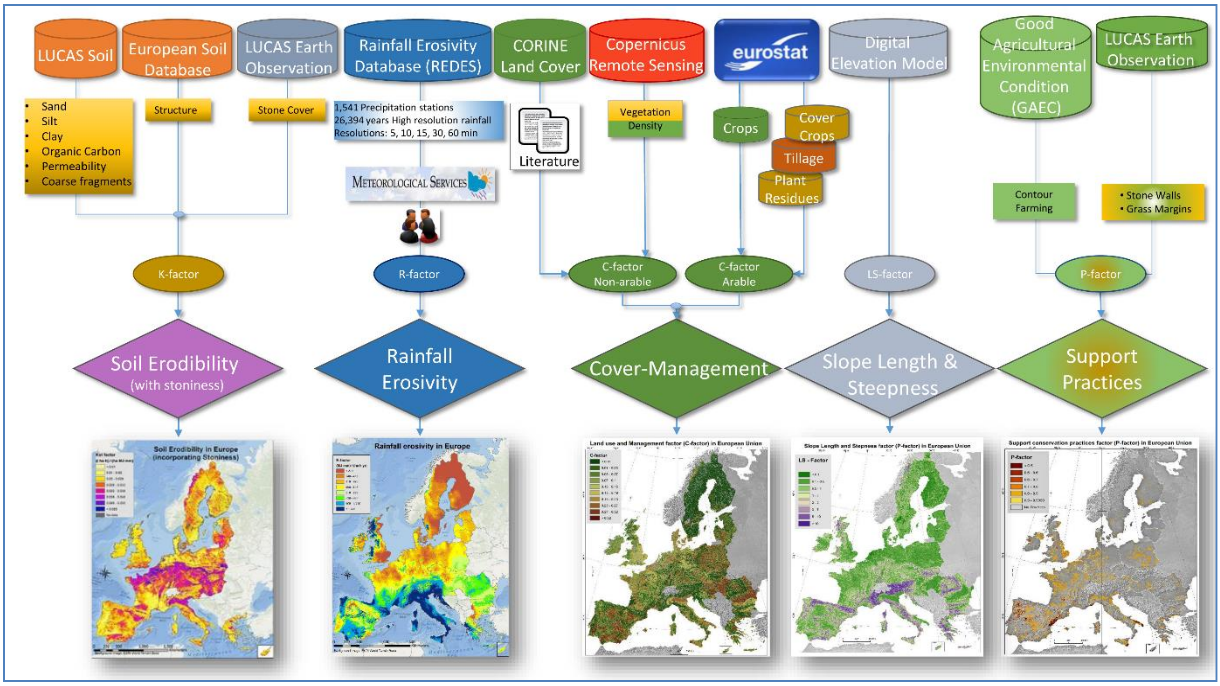
3.1 Revised Universal Soil Loss (RUSLE2015)

The RUSLE model (Renard et al., 1997) provides an estimate of possible erosion rates and estimates sediment delivery on the basis of accepted scientific knowledge, peer review published manuscripts, technical judgment and input datasets. In this assessment, the basic RUSLE model has been adapted through the improved quality of the input layers.

RUSLE2015 improves the quality of estimation by introducing updated (2010), high-resolution (100m) and peer-reviewed input layers of Rainfall Erosivity, Soil Erodibility, Slope Steepness and Slope Length, Land Cover and Management and the Support Practices applied to control erosion.

Rainfall Erosivity was calculated from high-resolution temporal rainfall data (at intervals of 5, 10, 15, 30 and 60 minutes) collected from 1,541 well-distributed precipitation stations across Europe. Soil Erodibility is estimated for the 20,000 field sampling points including in the Land Use/Cover Area frame (LUCAS) survey. The Land Cover and management accounts for the influence of land use (mainly vegetation type/cover and crop type) and management practices (mainly in arable lands) with the potential to reduce the rate of soil erosion by water. The Slope Steepness and Slope Length parameters have been calculated using a high resolution Digital Elevation Model (DEM) at 25m. The support practices were estimated for the first time at European level taking into consideration the Good Agricultural and Environmental Conditions (GAEC). The model is documented in the European Soil Data Centre (ESDAC), plus in 10 peer review Open Access publications.

Figure 1. RUSLE 2015 Model workflow



<u>Input data sources used for the model</u>:

LUCAS Topsoil 2009, European Soil Database, CORINE Land Cover 2012, Rainfall Erosivity Database in Europe (REDES), Copernicus Remote Sensing, Eurostat Statistics (crops, Tillage, cover crops, plant residues), Digital Elevation Model (DEM), Good Agricultural Environmental Conditions (GAEC), LUCAS Earth Observations 2012.

The revised version of the RUSLE (RUSLE2015,), calculates mean annual soil loss rates by sheet and rill erosion according to the following equation:

$$E = R * K * C * LS * P$$

Where E: Annual average soil loss (t ha^{-1} yr^{-1}),

R: Rainfall Erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}),

K: Soil Erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}),

C: Cover-Management factor (dimensionless),

LS: Slope Length and Slope Steepness factor (dimensionless),

P: Support practices factor (dimensionless).

Each of the input factors is modelled using pan-European harmonized datasets as inputs.

3.1.1 Rainfall Erosivity factor (R-factor)

Input for Rainfall Erosivity factor: The Rainfall Erosivity Database at European Scale (REDES) which has been developed using high-temporal resolution rainfall data (at 5 min, 10-min, 15-min, 30-min, 60 minute intervals) from 1,541 stations across the European Union and Switzerland.

Methodology: The intensity of precipitation is one of the main factors affecting soil water erosion processes. R is a measure of the precipitation's erosivity and indicates the climatic influence on the erosion phenomenon through the mixed effect of rainfall action and superficial runoff, both laminar and rill. Wischmeier (1959) identified a composite parameter, EI30, as the best indicator of Rainfall Erosivity. It is determined, for the ki-th rain event of the i-th year, by multiplying the kinetic energy of rain by the maximum rainfall intensity occurred within a temporal interval of 30 minutes.

In RUSLE20015, the R-factor is calculated based on high-resolution temporal rainfall data (5, 10, 15, 30 and 60 minutes) collected from 1,541 well-distributed precipitation stations across Europe (Panagos et al., 2015). This first Rainfall Erosivity Database at the European Scale (REDES) was a major advancement in calculating Rainfall Erosivity in Europe. The precipitation time series used ranged from 7 to 56 years, with an average of 17.1 years. The time-series precipitation data of more than 75% of European Union (EU) countries cover the decade 2000-2010. Gaussian Process Regression (GPR) (Rasmussen and Williams, 2006) has been used to interpolate the R-factor station values to a European Rainfall Erosivity map at 500m resolution. The covariates used for the R-factor interpolation were climatic data (total precipitation, seasonal precipitation, precipitation of driest/wettest months, average temperature), elevation and latitude/longitude. The mean R-factor for the EU plus Switzerland is 722 MJ mm ha^{-1} h^{-1} yr^{-1}, with the highest values (>1,000 MJ mm ha^{-1} h^{-1} yr^{-1}) in the Mediterranean and alpine regions while the lowest values (500 MJ mm ha-1 h^{-1} yr^{-1}) are founds in the Nordic countries.

3.1.2 Soil Erodibility factor (K-factor)

Input for Soil Erodiblity factor: LUCAS topsoil database 2009 (and update 2012 for Romania and Bulgaria) and European Soil Database v.2 (Soil structure).

Methodology: The greatest obstacle to soil erosion modelling at larger spatial scales is the lack of data on soil characteristics. One key parameter for modelling soil erosion is the soil erodibility, expressed as the K-factor in the widely used models such as the Universal Soil Loss Equation (USLE) and its revised version (RUSLE). The K-factor is related to soil properties such as organic matter content, soil texture, soil structure and permeability. The LUCAS 2009 survey provides a pan-European soil dataset consisting of around 20,000 points across 27 Member States of the European Union.

JRC generated the first harmonised high-resolution Soil Erodibility map (with a grid cell size of 500 m) for the 28 EU Member States. Soil Erodibility was calculated for the LUCAS survey points using the monograph of Wischmeier and Smith (1978). A Cubist regression model was applied to correlate spatial data such as latitude, longitude, remotely sensed and terrain features in order to develop a high-resolution Soil Erodibility map. The mean K-factor for Europe was estimated at 0.032 t ha h ha^{-1} MJ^{-1} mm^{-1} with a standard deviation of 0.009 t ha h ha^{-1} MJ^{-1} mm^{-1}. The resulting Soil Erodibility dataset compared well with published local and regional Soil Erodibility data. However, the incorporation of the protective effect of a surface stone cover, which is usually not considered for the Soil Erodibility calculations, resulted in an average 15% decrease of the K-factor. The exclusion of this effect in K-factor calculations is likely to result in an overestimation of soil erosion, particularly for the Mediterranean countries, where the highest percentages of surface stone cover were observed.

3.1.3 Cover Management factor (C-factor)

Input for Cover Management factor: CORINE Land Cover 2000-2006-2012, COPERNICUS vegetation density layer, Eurostat statistical data on crops distribution, Tillage practices, Cover crops and Plant residues.

Methodology: Land use and management influence the magnitude of soil loss. Among the different soil erosion risk factors, the Cover Management factor (C-factor) is the one that policy makers and farmers can most readily influence in order to help reduce soil loss rates. The present study proposes a methodology for estimating the C-factor in the European Union (EU), using pan-European datasets (such as CORINE Land Cover), biophysical attributes derived from remote sensing, and statistical data on agricultural crops and practices.

In arable lands, the C-factor was estimated using crop statistics (% of land per crop) and data on management practices such as conservation tillage, plant residues and winter crop cover (provided by European census data). The C-factor in non-arable lands was estimated by weighting the range of literature values found according to fractional vegetation cover, which was estimated based on the remote sensing dataset Fcover (Fraction of green Vegetation Cover)coming from COPERNICUS. The mean C-factor in the EU is estimated to be 0.1043, with an extremely high variability; forests have the lowest mean C-factor(0.00116), and arable lands and sparsely vegetated areas the highest (0.233 and 0.2651, respectively). Conservation management practices (e.g. reduced or no tillage, use of cover crops and plant residues) lower the C-factor by on average 19.1% in arable lands. The methodology is designed to be a tool for policy makers to assess the effect of future land use and crop rotation scenarios on soil erosion by water. The impact of land use changes (deforestation, arable land expansion) and the effect of policies (such as the Common Agricultural Policy and the push to grow more renewable energy crops) can potentially be quantified with the proposed model.

3.1.4 Slope Length and Slope Steepness factor (LS-factor)

Input for Length and Slope Steepness factor: Digital Elevation model (DEM) at 25m resolution.

Methodology: The S-factor measures the effect of slope steepness, while the L-factor defines the impact of slope length. The combined LS-factor describes the effect of topography on soil erosion. The LS-calculation was performed using the original equation proposed by Desmet and Govers (1996) and implemented using the System for

Automated Geoscientific Analyses (SAGA), which incorporates a multiple flow algorithm and contributes to a precise estimation of flow accumulation. The LS-factor dataset was calculated using a high-resolution (25 m) Digital Elevation Model (DEM) for the whole European Union, resulting in an improved delineation of areas at risk of soil erosion as compared to lower-resolution datasets. This combined approach of using Geographic Information Systems (GIS) software tools with high-resolution DEMs has been successfully applied in regional assessments in the past, and is now being applied for first time at the European scale.

3.1.5 Support Practices factor (P-factor)

Input for support practices factor: LUCAS Earth Observation database 2012 (stone walls, grass margins), Good Agricultural Environmental Conditions (GAEC) database.

Methodology: The USLE/RUSLE support practice factor (P-factor) is rarely taken into account in soil erosion risk modelling at sub-continental scale, as it is difficult to estimate for large areas. This study attempts to model the P-factor in the EU. For this, it considers the latest policy developments in the Common Agricultural Policy, and applies the rules set by Member States for contour farming over a certain slope gradient. The impact of stone walls and grass margins is also modelled using more than 226,000 observations from the Land use/cover area frame statistical survey (LUCAS) carried out in 2012 in the EU. The mean P-factor considering contour farming, stone walls and grass margins in the EU is estimated at 0.9702. The Support Practices accounted for in the P-factor reduce the risk of soil erosion by 3%, with grass margins having the largest impact (57% of the total erosion risk reduction) followed by stone walls (38%). Contour farming contributes very little to the P-factor given its limited application; it is only used as a support practice in eight countries and only on very steep slopes. Support Practices have the highest impact in Malta, Portugal, Spain, Italy, Greece, Belgium, The Netherlands and United Kingdom where they reduce soil erosion risk by at least 5%. The P-factor modelling tool can potentially be used by policy makers to run soil-erosion risk scenarios for a wider application of contour farming in areas with slope gradients less than 10%, maintaining stone walls and increasing the number of grass margins under the forthcoming reform of the Common Agricultural Policy.

3.2 Uncertainties

Estimated data on soil erosion are published following a qualitative assessment and compared with EIONET country estimates showing that the model output matches general erosion patterns across Europe. However, quantitative validation is foreseen to take place against long-term erosion plots.

For each input layer, we have performed an uncertainty analysis and relevant maps of standard error have been produced. Moreover, in a sensitivity analysis that we have performed the most sensitive factor is the cover management followed by topographic and climate factors. This implies that the management practices followed by farmers can reduce soil erosion where applied.

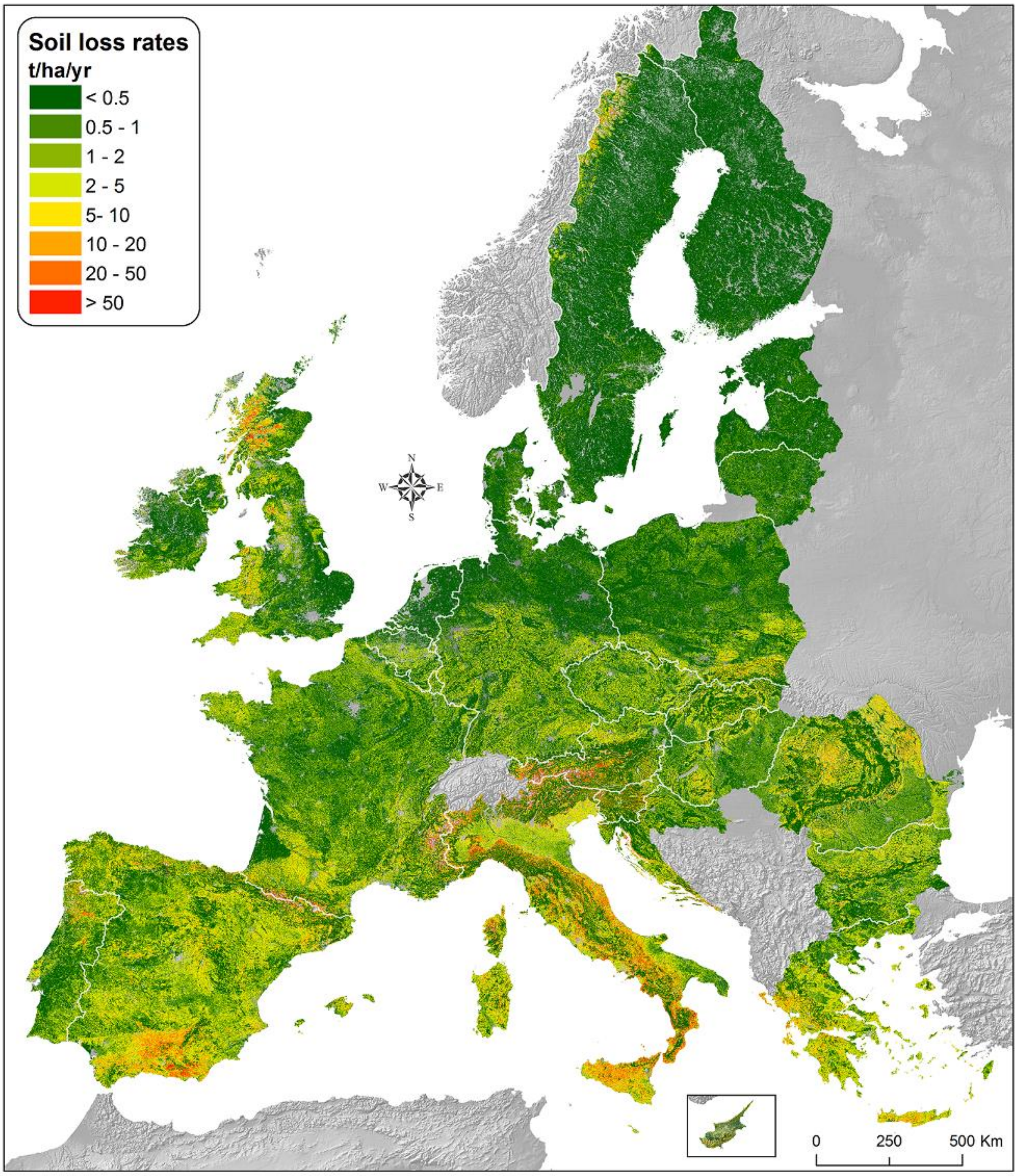
The major sources of uncertainty are found in some highly erosion-prone CORINE land-cover classes (e.g. sparsely vegetated areas) that demonstrate high variability between Mediterranean regions (badlands) and northern Europe (mixed vegetation with rocks). The use of remote sensing data on vegetation density has proven to be useful for fine-tuning the erosion-factor values. The soil loss predictions in steep and arid areas can be further improved by separating the effects of erodible soil from the effects of rock and gravel surfaces.

4 Results

In this section, we present the results as coming out from the RUSLE2015 model followed by the various outputs delivered to DG AGRI for the CAP context indicator.

A map of soil loss in the European Union produced using RUSLE2015 at 100 m resolution (Fig. 2). This resolution depends on the data availability of the input factors. The scale of 100 m pixel size was selected as being the most appropriate because the C-factor layer (at 100 m resolution) can be altered as a result of policy interventions that affect land use.

Figure 2. Map of soil loss rates in the European Union.



Soil loss potential is estimated for 90.3% of the EU surface (3,941 * 10^3 km^2 out of a total 4,366 * 10^3 km^2), as the remaining 9.7% consists of surfaces that are not prone to soil erosion, such as urban areas, bare rocks, glaciers, wetlands, lakes, rivers, inland waters and marine waters.

The mean annual rate of soil loss due to water erosion for the reference year 2012 is 2.40 t ha^{-1} yr^{-1} for the potentially erosion-prone land cover in the EU. The total annual soil loss by water erosion in the EU-28 is 970 Million tonnes. The RUSLE2015 has also been run with the CORINE Land Cover 2000 and the baseline scenario where no agricultural management practices are applied. According to the 2000 soil erosion data, the mean soil loss by water erosion was 2.71 t ha^{-1} yr^{-1}. The application of agricultural management practices (reduced tillage, crop residues, cover crops, grass margins, terraces and contour farming) have contributed to two thirds of this reduction (Panagos et al., 2016) while the remaining third is due to land cover change. The increase of forest and artificial surfaces between 2000 and 2012 is considered an important factor for decreasing erosion in EU (Robinson, 2017).

The average rate of soil loss falls to 2.16 t ha^{-1} yr^{-1} if the non-erosion-prone areas are included in the statistical analysis. In both cases, the average annual rate of soil loss is significantly higher than the average rate of soil formation in Europe of 1.4 t ha^{-1} yr^{-1} (Verheijen et al., 2009).

Soil erosion by water is among the agro-environmental indicators developed by the European Commission services for monitoring agricultural and environmental policies. The map of soil loss in the EU (Fig. 2) supports the statistical service Eurostat with aggregated data at various geographic levels (national, regional, provincial).

The Directorate-General for Agriculture and Rural Development (DG AGRI), which is responsible for the implementation of Common Agricultural Policy (CAP) in the EU, focuses on soil erosion in agricultural lands and requests indicators of soil erosion in agricultural lands. According to the definition of the indicator, JRC provides both the mean soil erosion rates and the Estimated agricultural area affected by moderate to severe water erosion (>11 t ha^{-1} yr^{-1}). Based on the requirements given, the classification of soil erosion data was based on CORINE Land Cover classes (2012): Total agricultural area (classes: 12-22+26), Arable and permanent crop area (classes: 12-17, 19-22), Permanent meadows and pasture (Classes: 18, 26).

The JRC provides the soil erosion indicator to DG AGRI for different NUTS level. Using the latest version (2013 dataset), JRC has developed factsheets for NUTS0 (Country), NUTS1, NUTS2 (regional) and NUTS3 (province) levels. An example of those factsheets is provided in Table 1 for NUTS0. The other three factsheets are provided to DG AGRI but it is not possible to fit in this document due to large number of provinces (1315 NUTS3), regions (265 NUTS2) and 95 NUTS1 areas.

Soil degradation by water erosion is particularly significant in some countries of southern Europe, namely in Italy (8.3 t ha^{-1} yr^{-1}), Greece (4.2 t ha^{-1} yr^{-1}), Malta (6 t ha^{-1} yr^{-1}) and Spain (3.7 t ha^{-1} yr^{-1}), but also in mountainous countries with high intensity of rain such as Slovenia (7.4 t ha^{-1} yr^{-1}) and Austria (7.3 t ha^{-1} yr^{-1}). Low levels (below 1 t ha^{-1} yr^{-1}) were registered Denmark, Estonia, Latvia, Lithuania, the Netherlands, Poland, Finland and Sweden. The rates of soil loss by water erosion at Member States level represent national average values and therefore may mask higher erosion rates in many areas even for those countries that have a low mean. The mean soil erosion rate is higher (2.7 t ha^{-1} yr^{-1}) in the old Member States area (EU-15) compared to the one (1.7 t ha^{-1} yr^{-1}) in the new Member states.

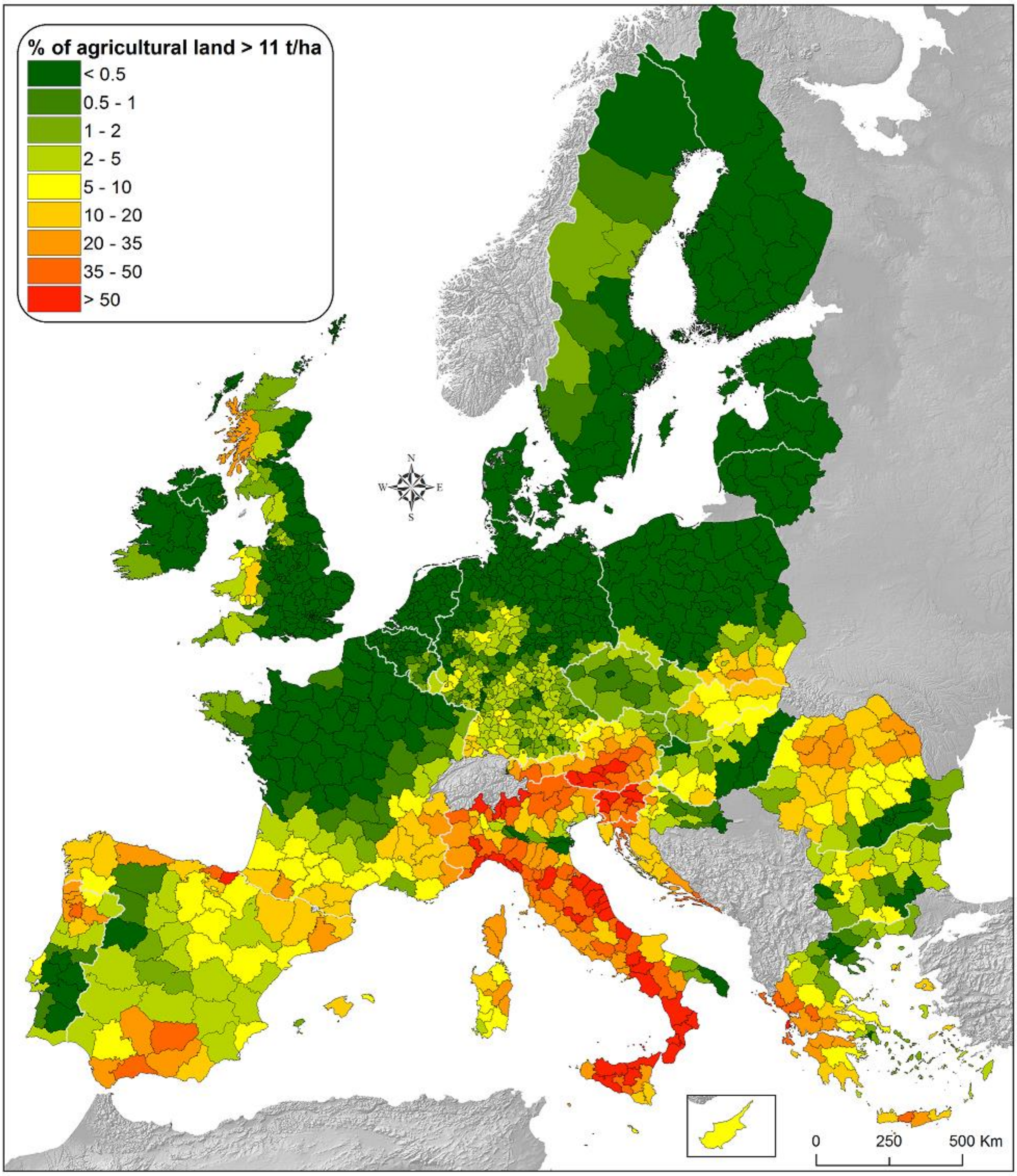
Table 1. CAP Context Indicator Soil erosion by water at NUTS0.

Data calculated using RUSLE Model. EU, National and regional data: 2012 (CLC2012).
Corine Land Cover classes: Total agricultural area (12-22 and 26), Arable and permanent crop area (12-17 and 19-22), Permanent meadows and pasture (18, 26).

Soil erosion by water		Agricultural areas at risk of soil erosion by water					
2012		2012			2012		
Country	Tonnes/ha/year	Estimated (ha) agricultural area affected by moderate to severe water erosion (>11 t/ha/yr)			Estimated (%) agricultural area affected by moderate to severe water erosion (>11 t/ha/yr)		
		Total agricultural area	Arable and permanent crop area	Permanent meadows and pasture	Total agricultural area	Arable and permanent crop area	Permanent meadows and pasture
		ha			% of total area in each category		
EU-28	2.40	14137.2	12025.5	2111.8	6.7	7.5	4.2
BE	1.22	6.9	6.5	0.4	0.4	0.5	0.1
BG	2.03	204.7	191.6	13.1	3.3	3.6	1.6
CZ	1.62	65.7	63.2	2.5	1.5	1.7	0.3
DK	0.50	0.1	0.1	0.0	0.0	0.0	0.0
DE	1.18	286.9	242.7	44.2	1.4	1.7	0.7
EE	0.21	0.1	0.1	0.0	0.0	0.0	0.0
IE	1.12	14.7	6.7	8.0	0.3	0.8	0.2
EL	4.19	657.9	607.4	50.5	10.7	12.1	4.4
ES	3.73	2633.1	2381.2	251.9	9.6	10.5	5.3
FR	2.25	973.3	679.5	293.8	2.9	2.8	3.0
HR	3.03	238.7	183.2	55.5	9.4	9.2	10.4
IT	8.35	5574.1	5043.6	530.6	32.7	33.0	29.4
CY	2.94	33.5	33.4	0.1	7.2	7.6	0.4
LV	0.33	0.2	0.2	0.0	0.0	0.0	0.0
LT	0.49	0.6	0.6	0.0	0.0	0.0	0.0
LU	2.08	4.7	4.5	0.2	3.4	4.5	0.5
HU	1.57	166.3	162.4	3.9	2.6	3.0	0.4
MT	6.00	1.5	1.5	0.0	9.6	9.6	0.0
NL	0.27	0.1	0.1	0.0	0.0	0.0	0.0
AT	7.32	690.6	243.7	446.9	21.0	12.2	34.3
PL	0.93	258.0	257.0	1.0	1.4	1.6	0.0
PT	2.21	231.8	229.9	1.9	5.4	5.6	1.1
RO	2.86	1373.2	1248.0	125.2	9.7	11.2	4.1
SI	7.41	306.9	242.4	64.4	42.4	41.2	47.4
SK	2.12	158.9	152.1	6.8	6.8	7.4	2.4
FI	0.05	0.1	0.1	0.0	0.0	0.0	0.0
SE	0.39	13.2	12.3	0.9	0.3	0.3	0.2
UK	2.07	241.2	31.2	210.0	1.6	0.5	2.5

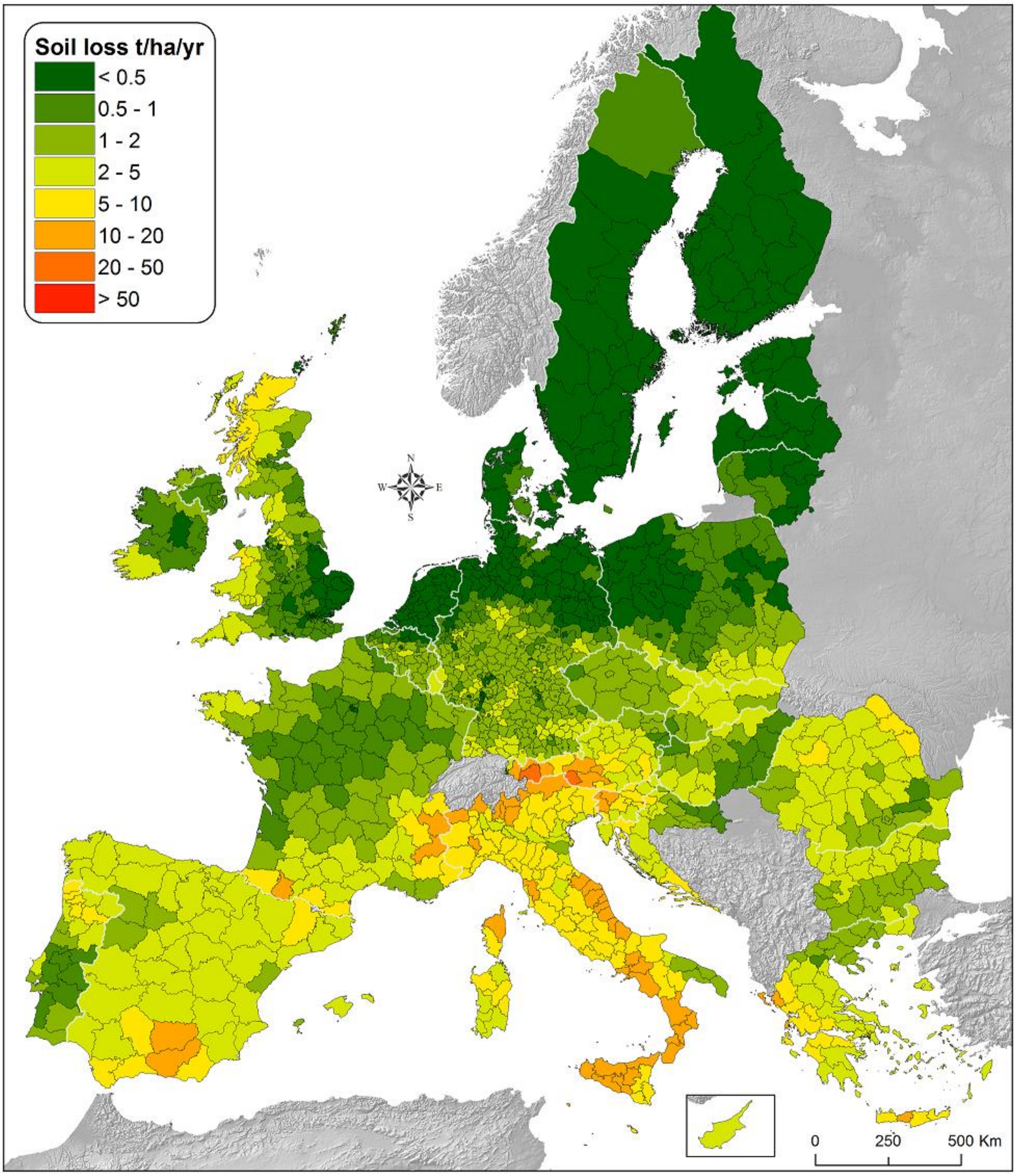
An example of the data provided for the CAP context indicator is presented in Figure 3. The map shows the NUTS3 base on the percentage of agricultural land which is threatened under severe erosion (> 11 t^{-1} ha^{-1}).

Figure 3. The % of agricultural land under severe erosion (> 11 t^{-1} ha^{-1}) at NUTS3 level.



In addition, the mean soil erosion rates can be estimated also at NUTS3 level and are part of the CAP context Indicator Soil Erosion (Figure 4).

Figure 4. Mean soil loss by water erosion at NUTS3 level.



The RUSLE2015 model can be run with the CORINE Land Cover 2000 but leaving out the impact of agricultural management practices which are mainly applied after 2003. Since no statistical data were available about reduced tillage, soil cover, contour farming, terracing and grass margins before the GAEC implementation in 2003, we hypothesised that those management practices were previously not applied or were only applied to a very limited extent.

The difference between the 2000 and 2012 soil erosion rates show the impact of management practices in reducing erosion and/or the impact of natural land cover change (increase of forestlands and artificial land, decrease of agricultural lands). The change in the rate of soil loss by water erosion is shown in Table 2.

Table 2. Change in the rate of soil loss by water erosion in the period 2000-2012.

Indicator	C.42 - Soil erosion by water	Change in the rate of soil loss by water erosion
Measurement	Estimated rate of soil loss by water erosion	Change
Source	JRC (RUSLE Model)	JRC (RUSLE Model)
Year	2012	2000-2012
Unit	t/ha/yr	t/ha/yr
Country		
Belgium	1.22	-0.21
Bulgaria	2.03	-0.52
Czech Republic	1.62	-0.47
Denmark	0.50	-0.05
Germany	1.18	-0.42
Estonia	0.21	-0.03
Ireland	1.12	0.13
Greece	4.19	-0.27
Spain	3.73	-0.77
France	2.25	-0.27
Croatia	3.03	-0.25
Italy	8.35	-0.83
Cyprus	2.94	-0.63
Latvia	0.33	0.00
Lithuania	0.49	-0.05
Luxembourg	2.08	-0.23
Hungary	1.57	-0.20
Malta	6.00	-4.52
Netherlands	0.27	-0.04
Austria	7.32	0.35
Poland	0.93	-0.13
Portugal	2.21	-0.36
Romania	2.86	-0.15
Slovenia	7.41	-0.24
Slovakia	2.12	-0.32
Finland	0.05	-0.02
Sweden	0.39	-0.02
United Kingdom	2.07	-0.20
EU-28	2.40	-0.31
EU-15	2.65	-0.31

EU-N13	1.73		-0.23

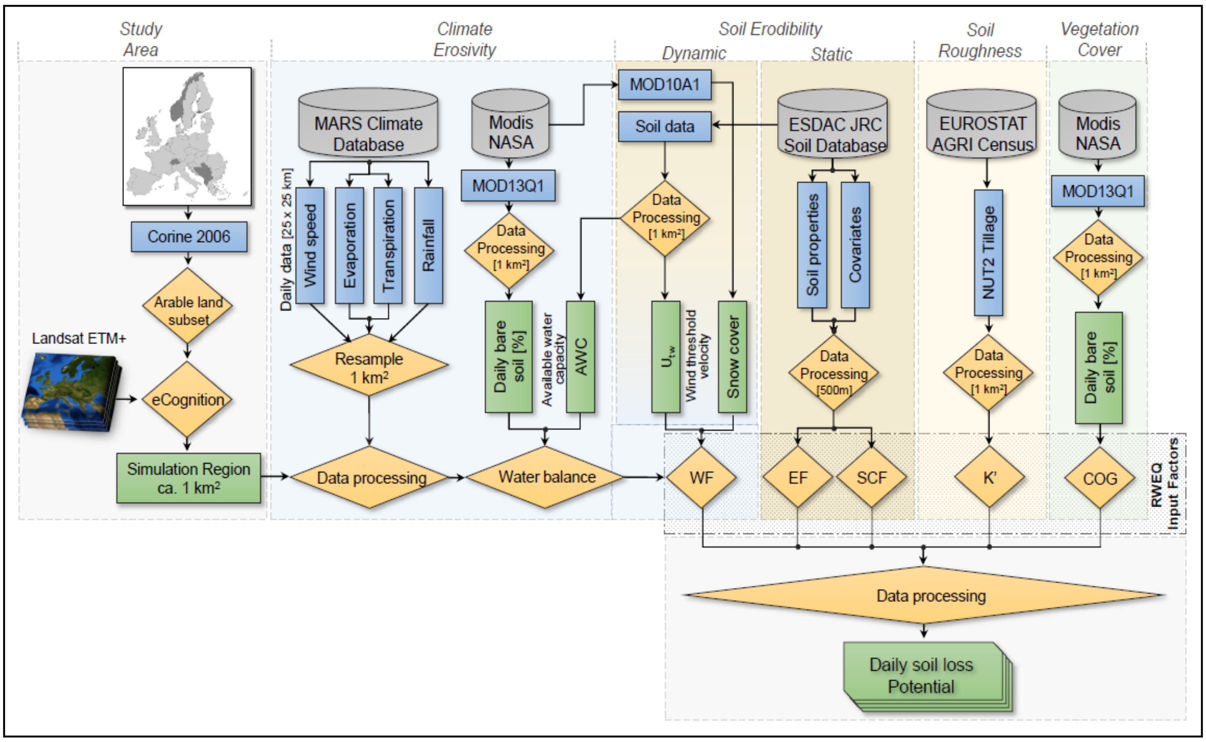
5 Wind Erosion

Wind erosion mainly occurs in dry conditions when the soil is exposed to wind (Webb et al., 2006). It is forced when the movement of soil by wind takes place and the finest particles (organic matter, clay and loam) are entrained and transported in long distances by wind (Shao, 2008). In recent times, intensive farming has increased the frequency and magnitude of this geomorphic process with consequences especially for sensitive lands (Funk and Reuter, 2006). After the 1970's, intensive crop cultivation, increased mechanisation, enlargement of field sizes, removal of hedges, high residues/biomass exploitation of vegetation and consecutive bare fallow years in cultivated lands, intensified the negative effects of wind erosion (Colazo and Buschiazzo, 2015). In fact, wind erosion is also a phenomenon relevant for Europe although this land degradation process has been overlooked until very recently (Funk and Reuter, 2006).

5.1 Wind Erosion model description

The Revised Wind Erosion Equation (RWEQ) is a combination of empirical and process-based modelling developed to estimate the soil loss for agricultural fields in the USA (Fryrear et al., 2000). Wind is the basic driving force in the model. The Revised Wind Erosion Equation (RWEQ) is relatively simple and requires a limited amount of input data, which makes it suitable for upscaling (Zobeck et al., 2000; Youssef et al., 2012).

Figure 5. Model structure of GIS-Revised Wind Equation (GIS-RWEQ). WF: weather factor; EF: wind-erodible fraction of soil; SCF: soil crust factor; K': soil roughness factor and COG: combined crop factors.



In the pan-European study, the GIS version of the RWEQ (named GIS-RWEQ) has been developed to quantitatively assess soil loss by wind over large study areas and to evaluate the reliability of its results (Borrelli et al., 2017). The GIS-RWEQ model and available datasets were used to compute soil loss rates in the arable land of EU-28 between January 2001 and December 2010. The GIS-RWEQ model reproduces the main components of RWEQ in a GIS environment (Borrelli et al., 2017).

The GIS-RWEQ model estimates wind erosion potential at 1km x 1km grid cell. The material and methods employed for the GIS-RWEQ are reported in the publication of Borrelli et al., 2017. The main input factors in the model are climatic erosivity, soil erodibility, vegetation cover and landscape roughness (Fig. 5). In practice the model included the following group of data layers:

Climate: Wind velocity, rainfall and evapotranspiration.

Soil characteristics: Sand, silt, clay, calcium carbonate ($CaCO_3$), organic matter, water-retention capacity and soil moisture.

Land use (vegetation cover): Land use type, percent of vegetation cover and landscape roughness.

5.2 Results and proposed data for support to CAP context indicators

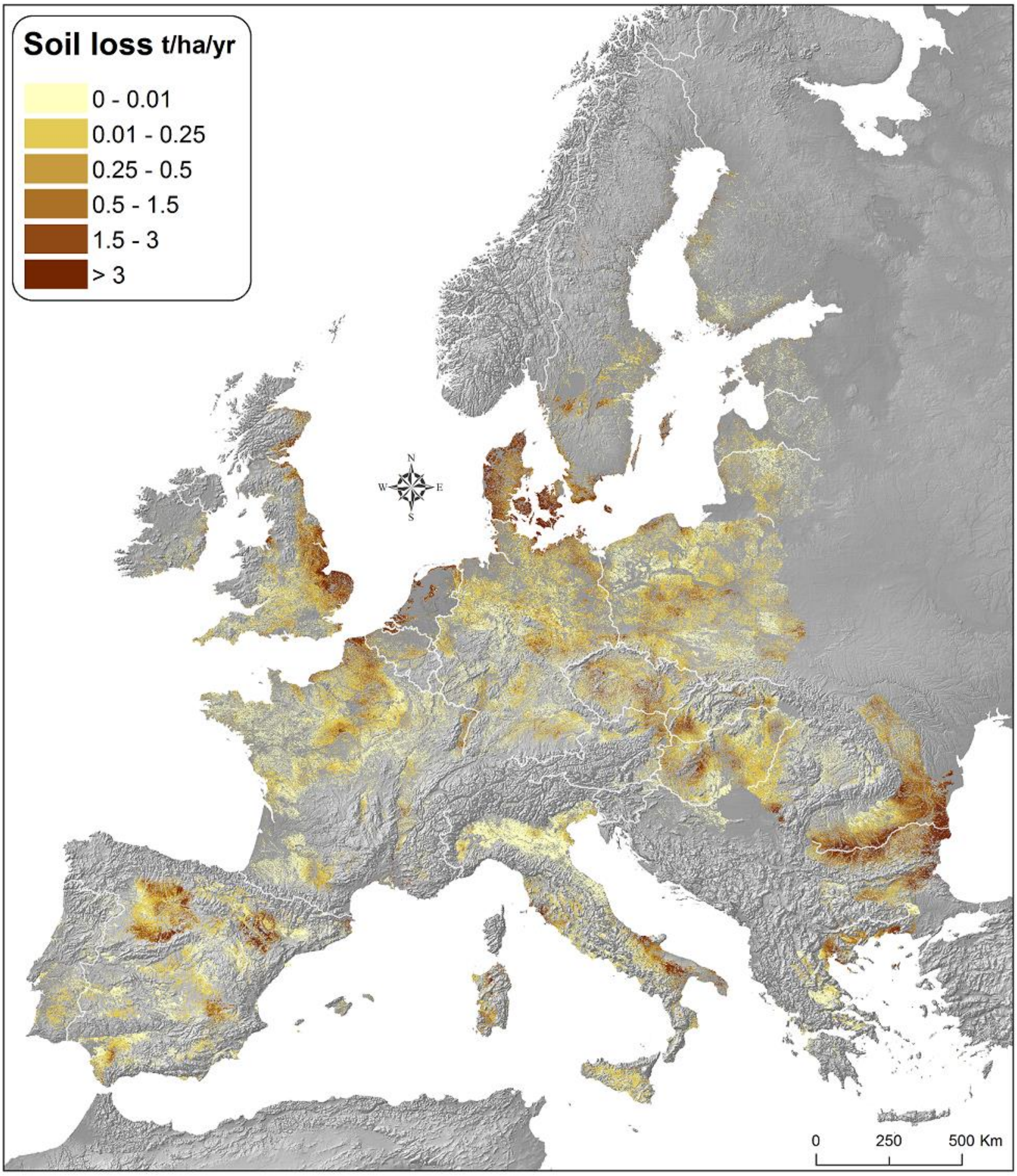
The soil loss potential due to wind erosion was estimated by the GIS-RWEQ for more than 1 million cells (ca. 1 km spatial resolution) into which the arable land of the EU-28 was subdivided. The model was run only in the arable lands, which are classified in CORINE Land Cover as arable lands irrigated and non-irrigated (Classes: 12 and 13). The reason for that is the presence of wind erosion in arable lands.

The average annual soil loss rates predicted for the period 2001–2010 totalled 0.53 t ha^{-1} yr^{-1}. More than half of the study area has estimated wind erosion of less than 0.3 t ha^{-1} yr^{-1}. The spatial pattern of soil erosion was divided into six classes defined according to the soil loss data distribution (quintiles) (Figure 6). Approximately a third (36.3%) of the investigated arable land showed no sign of erosion (Figure 3). About 33.7% and 8.2% of the study area, respectively, were subject to very low and low soil erosion, whereas 12.2% were characterised by slight erosion. For the remaining 9.7% of arable land, moderate (5.3%) and high (4.4%) wind erosion rates were predicted.

The modelling results indicated a pronounced temporal variability of soil loss rates. While different patterns across the countries could be observed, the temporal distribution of wind erosion throughout the year at a European level showed the highest values during the winter period. Soil loss rates were at their peak between December and February, accounting for approximately 57% of the total losses. In spring, the monthly soil loss values decreased hitting their minimum in May. This temporal pattern depends much on the weather factor (wind).

The model performance was checked with published studies. The cross-check of the modelling results showed that the predicted soil loss rates were generally in agreement with the wind erosion sites reported in literature. During the evaluation of the model performances, it turned out that 94.4% of the 90 wind erosion-sensitive locations reported in literature were also classified by the GIS-RWEQ model as being affected by wind erosion.

Figure 6. Potential wind soil loss modelled for the European arable land.



The modelling outcomes suggest that wind erosion is a common process in most countries. A cross-country analysis (Table 3) showed the highest annual soil loss rate in Denmark (3 t ha^{-1} yr^{-1}), the Netherlands (2.6 t ha^{-1} yr^{-1}), Bulgaria (1.8 t ha^{-1} yr^{-1}) and to a lesser extent also in the Romania and United Kingdom (Table 3).

The estimated wind erosion rates are referring to the arable land irrigated and non-irrigated (Corine Land Cover classes: 12, 13). The total annual soil loss by wind erosion in the EU-28 is 53 Million tonnes which is about 1/20 compared to soil loss by water erosion. However, the water erosion in the arable land irrigated and non-irrigated (Corine

Land Cover classes: 12, 13) is about 295 million tonnes which is c.a six times higher compared to the wind erosion taken place in those areas.

With regard to the agricultural areas with severe wind erosion (> 11t ha^{-1} yr^{-1}), in the case of wind erosion it is very limited (0.27%).

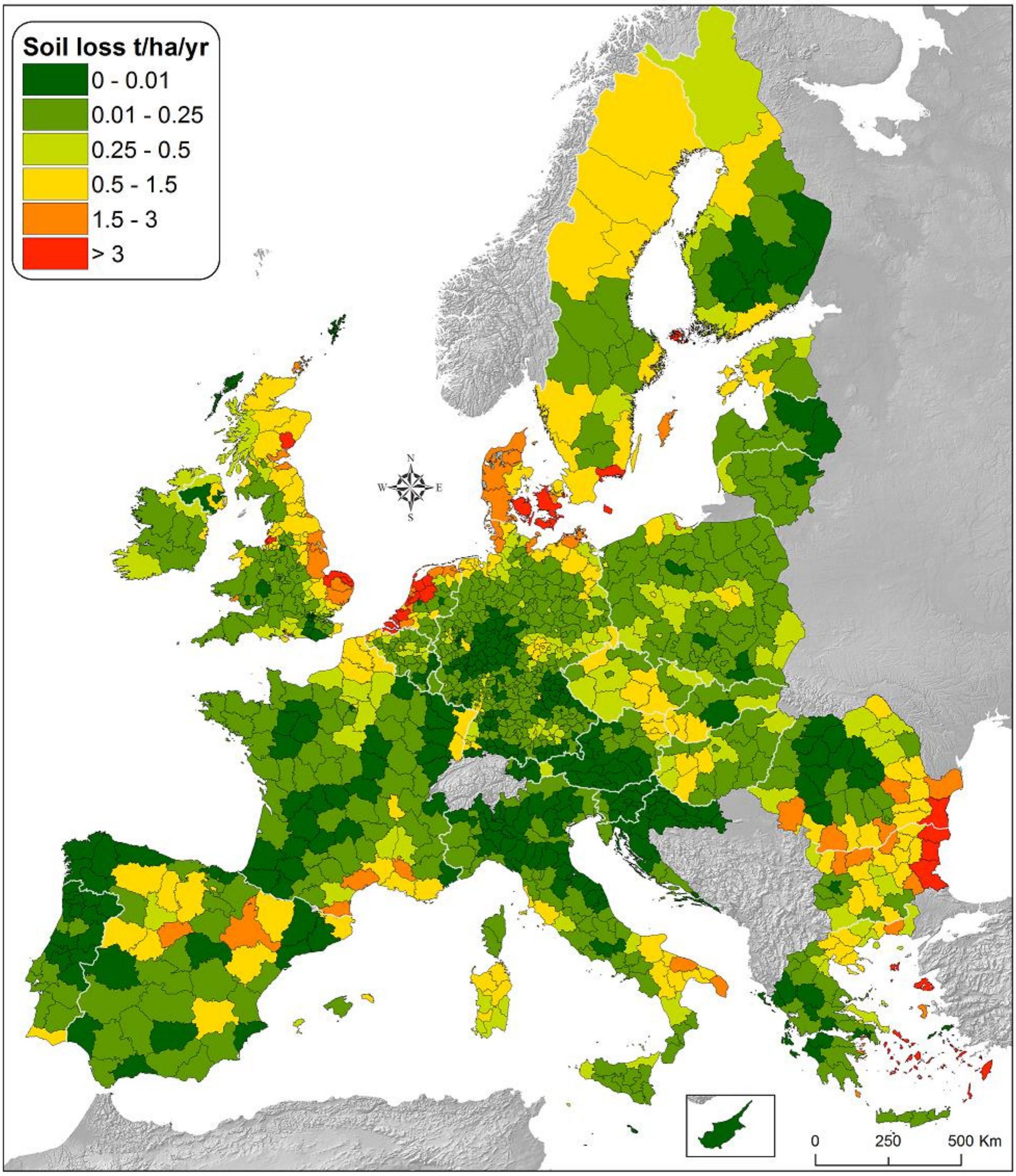
The average rate of soil loss falls to 0.12 t ha^{-1} yr^{-1} if the non-erosion-prone areas (all land uses) are also included in the statistical analysis.

Table 3. Wind erosion rates at NUTS0 and estimated arable land suffering from severe wind erosion.

Data calculated using GIS-RWEQ wind Erosion Model. EU, National and regional data: 2001-2010. Corine Land Cover classes: Arable land irrigated and non-irrigated (12 and 13)				
Soil erosion by wind		**Agricultural areas at risk of soil erosion by wind erosion**		
2001-2010		**2001-2010**		
Country	**tonnes/ha/year**	**Estimated arable land affected by moderate to severe wind erosion (>11 t/ha/yr)**		
		Arable land (CLC: 12,13)	**Arable Land with wind erosion > 11t**	**% of arable land area**
		ha	**ha**	**%**
EU-28	**0.53**	**100,637,975**	**279,915**	**0.27**
AT	0.26	1,089,951	0	0.0
BE	0.31	530,550	0	0.0
BG	1.84	3,560,758	97,026	2.7
CZ	0.45	2,721,872	0	0.0
CY	0.00	256,195	0	0.0
DE	0.26	12,486,266	13,223	0.1
DK	3.01	2,649,231	71,009	2.7
EE	0.27	476,113	86	0.0
EL	0.55	1,998,472	4,980	0.2
ES	0.43	11,241,932	9,359	0.1
FI	0.33	1,260,390	429	0.0
FR	0.19	14,049,153	2,404	0.0
HR	0.00	344,570	0	0.0
HU	0.27	4,535,051	0	0.0
IE	0.25	476,113	258	0.1
IT	0.27	7,878,059	1,631	0.0
LT	0.10	1,761,918	0	0.0
LU	0.02	26,274	0	0.0
LV	0.07	773,973	0	0.0
MT	0.00	86	0	0.0
NL	2.61	711,379	23,269	3.3
PL	0.18	12,344,419	86	0.0
PT	0.06	1,120,003	0	0.0
RO	0.95	7,613,771	12,794	0.2
SE	0.74	2,740,848	6,182	0.2
SI	0.01	108,274	0	0.0
SK	0.39	1,521,329	0	0.0
UK	1.03	6,361,023	37,179	0.6

Similar results to the statistical data presented in Table 3 are available for the rest of NUTS classes (NUTS1, NUTS2 and NUTS3). An example of the wind erosion rates in the arable lands at NUTS3 level is presented in figure 7. Only few regions are susceptible to severe wind erosion rates (> 11 t ha^{-1} yr^{-1}) and they are mainly located in Denmark, Netherlands and Bulgaria.

Figure 7. Mean soil loss by wind erosion at NUTS3 level applied only in arable lands.



6 Conclusions and further developments

The results presented in this report shows how the modelling work on soil erosion has been evolved in JRC in order to develop an indicator in the context of Common Agricultural Policy (CAP). During the last 3 years, the JRC has developed the RUSLE2015 for estimating soil erosion by water and the GIS-RWEQ for the wind erosion. Both models have been presented briefly.

In this study, JRC presented some examples of the model outputs and how they are aggregated in order to develop relevant indicators. Similar to the development of the Soil Erosion by water CAP context indicator, the model outputs have also served to the development of Agro-environmental Indicators, Sustainable Development Goals (SDGs) 'Life on Land' indicator, Resource Efficiency Scoreboard, Regional statistics and the OECD indicators.

The current setting of RUSLE2015 model permits also to run scenario analysis based on climate change, land use change and policy interventions. According to current climate change projections and the research done on future rainfall erosivity, it is expected to have an increase in extreme rainfall events in the long future (2050-2070). This will trigger higher erosion and reduce agricultural productivity. The current land use projections estimate a slight increase of forests and urban lands in the expense of semi-natural or arable lands. However, this cannot compensate the increase of soil erosion due to climate change. The proposed modelling platform allows to estimate the impact of anti-erosion measures and environmental-friendly management practices in receding the soil erosion.

An important development is the integration of soil erosion model with the soil carbon one. High uncertainty still exits on terrestrial carbon balance components the role of erosion in the global carbon cycle. Although the agricultural soils may act as a source or sink of CO_2 depending on the assumptions, erosion seems to induce net carbon fluxes in the same order of current carbon gains from improved management (Borrelli et al., 2016). Ultimately, we strongly support the idea that erosion should be prevented or reduced by agricultural policies and sustainable management practices, in order to maintain the soils in stable and good conditions (Lal, 2014) and increase their resilience to human and natural perturbations.

Another important aspect is the potential spatial displacement and transport of soil sediments due to water erosion at European scale. It is important to estimate the soil loss and deposition rates by estimating sediment transfer and fluxes. So, the sediment delivery models (WaTEM/SEDEM) are coupled with the current estimates of soil erosion estimates.

Similar to the current modelling application in European Union, the JRC can contribute to the FAO global land degradation assessments.

References

Alewell, C., Egli, M. & Meusburger, K. 2015. An attempt to estimate tolerable soil erosion rates by matching soil formation with denudation in Alpine grasslands. Journal of Soils and Sediments 15, 1383–1399.

Ballabio, C., Panagos, P. & Monatanarella, L. 2016. Mapping topsoil physical properties at European scale using the LUCAS database. Geoderma 261, 110–123.

Ballabio, C., Borrelli, P., Spinoni, J., Meusburger, K., Michaelides, S., Beguería, S., Klik, A., Petan, S., Janecek, M., Olsen, P., Aalto, J., Lakatos, M., Rymszewicz, A., Dumitrescu, A., Tadić, M.P., Nazzareno, D., Kostalova, J., Rousseva, S., Banasik, K., L., Alewell, C. & Panagos, P. 2017. Mapping monthly rainfall erosivity in Europe. Sci. Total. Environ. 579, 1298–1315.

Borrelli, P., Ballabio, C., Panagos, P. & Montanarella, L. 2014. Wind erosion susceptibility of European soils. Geoderma 232, 471–478.

Borrelli, P., Robinson, D. A., Fleischer, L. R., Lugato, E., Ballabio, C., Alewell, C., ... & Panagos, P. (2017). An assessment of the global impact of 21st century land use change on soil erosion. Nature Communications, 8, 2013

Borrelli, P., Märker, M., Panagos, P. & Schütt, B. 2014. Modeling soil erosion and river sediment yield for an intermountain drainage basin of the Central Apennines, Italy. Catena 114, 45–58.

Borrelli, P., Paustian, K., Panagos, P., Jones, A., Schütt, B. & Lugato, E. 2016. Effect of good agricultural and environmental conditions on erosion and soil organic carbon balance: a national case study. Land Use Policy 50, 408–421.

Borrelli, P., Panagos, P., Langhammer, J., Apostol, B. & Schütt, B. 2016. Assessment of the cover changes and the soil loss potential in European forestland: first approach to derive indicators to capture the ecological impacts on soil-related forest ecosystems. Ecological Indicators 60, 1208–1220.

Borrelli, P., Lugato, E., Montanarella, L. & Panagos, P. 2017. A new assessment of soil loss due to wind erosion in European agricultural soils using a quantitative spatially distributed modelling approach. Land Degradation and Development 28, 335–344.

Borrelli, P., Panagos, P., Ballabio, C., Lugato, E., Weynants, M., & Montanarella, L. 2016. Towards a pan-European assessment of land susceptibility to wind erosion. Land Degradation & Development 27, 1093–1105

Borrelli, P., Paustian, K., Panagos, P., Jones, A., Schütt, B. & Lugato, E. 2016. Effect of Good Agricultural and Environmental Conditions on erosion and soil organic carbon balance: A national case study. Land Use Policy 50, 408–421.

Colazo J.C. & Buschiazzo D. 2015. The impact of agriculture on soil texture due to wind erosion. Land Degradation and Development 26, 62–70.

Desmet, P. & Govers, G. 1996. A GIS procedure for automatically calculating the ULSE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation 51, 427–433.

Funk, R. & Reuter H.I. 2006. *Wind erosion*. In Soil erosion in Europe, Boardman J, Poesen J (eds). Wiley: Chichester, 563–582.

Lugato, E., Panagos, P., Bampa, F., Jones, A. & Montanarella, L. 2014. A new baseline of organic carbon stock in European agricultural soils using a modelling approach. Global Change Biology 20, 313–326.

Lugato, E., Bampa, F., Panagos, P., Montanarella, L. & Jones, A. 2014. Potential carbon sequestration of European arable soils estimated by modelling a comprehensive set of management practices. Global Change Biology 20, 3557–3567

Lugato, E., Paustian, K., Panagos, P., Jones, A. & Borrelli, P. 2016. Quantifying the erosion effect on current carbon budget of European agricultural soils at high spatial resolution. Glob. Change Biol. 22, 1976–1984.

Orgiazzi et al., 2017. LUCAS Soil, the largest expandable soil dataset for Europe: a review. European Journal of Soil Science, In press. DOI: 10.1111/ejss.12499

Panagos, P., Van Liedekerke, M., Jones, A. & Montanarella, L. 2012. European Soil Data Centre: response to European policy support and public data requirements. Land Use Policy 29, 329–338.

Panagos, P., Meusburger, K., Van Liedekerke, M., Alewell, C., Hiederer, R. & Montanarella, L. 2014. Assessing soil erosion in Europe based on data collected through a European Network. Soil Science and Plant Nutrition 60, 15–29.

Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P. & Alewell, C. 2014. Soil erodibility in Europe: a high-resolution dataset based on LUCAS. Science of Total Environment 189–200

Panagos, P., Ballabio, C., Borrelli, P., Meusburger, K., Klik, A. et al. 2015. Rainfall erosivity in Europe. Science of Total Environment 511, 801–814.

Panagos, P., Borrelli, P., Meusburger, C., Alewell, C., Lugato, E. & Montanarella, L. 2015. Estimating the soil erosion cover-management factor at European scale. Land Use Policy 48, 38–50

Panagos, P., Borrelli, P. & Meusburger, K. 2015. A new European slope length and steepness factor (LS-Factor) for modeling soil erosion by water. Geosciences 5, 117–126.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. 2016. Reply to "The new assessment of soil loss by water erosion in Europe. Panagos P. et al., 2015 Environ. Sci. Policy 54, 438–447—A response" by Evans and Boardman [Environ. Sci. Policy 58, 11–15]. Environmental Science & Policy 59, 53–57

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & vAlewell, C. 2016. Reply to the comment on "The new assessment of soil loss by water erosion in Europe" by Fiener & Auerswald. Environmental Science & Policy 57, 143–150

Panagos, P., Borrelli, P. & Robinson, D.A., Common Agricultural Policy: Tackling soil loss across Europe. Nature 526, 195, doi:10.1038/526195d

Panagos, P., Borrelli, P., Meusburger, K., van der Zanden, E.H., Poesen, J. & Alewell, C. 2015. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European Scale. Environmental Science& Policy 51, 23–34.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K. & Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. Environ. Sci. Policy 54, 438–447.

Panagos, P., Imeson, A., Meusburger, K., Borrelli, P., Poesen, J. & Alewell, C. 2016. Soil conservation in Europe: wish or reality? Land Degradation & Development 27, 1547–1551.

Panagos, P., Ballabio, C., Meusburger, K., Spinoni, J., Alewell, C. & Borrelli, P. 2017. Towards estimates of future rainfall erosivity in Europe based on REDES and WorldClim datasets. Journal of Hydrology 548, 251–262.

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P. & Smith, P. 2016. Climate smart soils. Nature 532, 49–57

Renard, K., Foster, G., Weesies, G., McCool, D. & Yoder, D. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agricultural Handbook No. 703. 404

Shao Y. 2008. Physics and modelling of wind erosion. Springer: Cologne

Tóth, G., Jones, A. & Montanarella, L. 2013. LUCAS Topsoil Survey. Methodology, Data and Results. JRC Technical Reports Number 26102. Publications Office of the European Union, Luxembourg

Verheijen, F.G.A., Jones, R.J.A., Rickson, R.J. & Smith, C.J. 2009. Tolerable versus actual soil erosion rates in Europe. Earth-Science Reviews 94, 23–38.

Webb N.P., McGowan H.A., Phinn S.R. & McTainsh G.H. 2006. AUSLEM (AUStralian Land Erodibility Model): a tool for identifying wind erosion hazard in Australia. Geomorphology 78, 179–200.

Wischmeier, W. & Smith, D. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. Agricultural Handbook No. 537 U.S. Department of Agriculture, Washington DC, USA.

List of abbreviations and definitions

RUSLE	Revised Universal Soil Loss Equation
RWEQ	Revised Wind Erosion Equation
GIS	Geographic Information System
CAP	Common Agricultural Policy
NUTS	Nomenclature of Territorial Units for Statistics
CORINE	Coordination of Information on the Environment Land Cover
LUCAS	Land Use and Coverage Area frame Survey

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