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Integrated spatial assessment of wind erosion risk in Hungary

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Abstract

Wind erosion susceptibility of the Hungarian soils was mapped on national level integrating three pillars of the complex phenomenon of deflation. Results of wind tunnel experiments on erodibility of various and representative soil samples were used for the parametrization of countrywide map of soil texture compiled for the upper 5 centimeter layer of soil, which resulted in a map representing threshold wind velocity exceedance. Average wind velocity was spatially estimated with 0.5' resolution using the MISH method elaborated for the spatial interpolation of surface meteorological elements. The ratio of threshold wind velocity exceedance was determined based on values predicted by the soil texture map at the grid locations. Ratio values were further interpolated to a finer 1 ha resolution using sand and silt content of the uppermost (0-5 cm) soil as spatial co-variables. Land cover was also taken into account excluding areas which are not relevant from the aspect of wind erosion (forests, water bodies, settlements etc.) to spatially assess the risk of wind erosion. According to the resulted map of wind erosion susceptibility, about 10% of the total area of Hungary can be identified as susceptible for wind erosion. The map gives more detailed insight into the spatial distribution of wind-affected areas in Hungary as opposed to former works.

Introduction

Wind erosion represents a serious problem worldwide: according to a report by the United Nations Environment Programme in 1991, the phenomenon of wind erosion is responsible for more than 46% of the total degradation of arid areas (Zheng, 2009). According to Lal (1994), the total agricultural area affected by wind erosion adds up to about 550 million hectares worldwide. Oldeman et al (1991) estimated the total European agricultural areas eroded by wind at 42 million hectares. In Europe, wind erosion affects mainly the semi-arid areas (López et al., 1998; Gomes et al., 2003) but the temperate climate areas of the northern European countries are also endangered (Eppink & Spaan, 1989; Goossens, 2001; Bärring et al., 2003). In agricultural lands, wind erosion manifests mainly in the removal and transport of the finest and biologically most active part of the soil, which is richest in organic matter and nutrients (Funk & Reuter, 2006). A substantial consequence is the decline in the productivity of endangered areas. Furthermore, the transport of nutrients and pre-sowing herbicides by wind erosion can also be considered as a serious environmental problem (Funk et al., 2004).

Wind erosion is usually a natural, geological process which forms many eolian landforms (Lancaster 1995), but nowadays it is accelerated by anthropogenic effects (overgrazing, mismanagement of agricultural lands, intensive crop cultivation etc.) Researches carried out in the 90's in Europe (Welsons: Gomes et al. 2003; Wheels: Böhner et al. 2003; Warren, 2003), revealed that wind erosion causes more serious problems, than it had been supposed earlier. Very recently Borelli et al. (2014a,b) provided spatial assessment of land and soil susceptibility for wind erosion at a European scale.

Vegetation cover plays an important role preventing wind erosion (Armbrust and Bilbro 1997). The presence of the vegetation on the surface increases the turbulence close to the ground and therefore decreases wind velocity (Shao, 2008). If non-erodible plants cover the soil surface, soil erosion is reduced by 98% (Fryear et al. 2000). The vegetation can also increase the soil moisture content through shading effect. Bare soil and arable lands are the most seriously affected by wind erosion. Because vegetation cover alters in space and time, it is more straightforward to characterize an area only with the potential exposure, which can be characterized by susceptibility to wind erosion.

In Hungary wind erosion causes serious problems in agricultural production as well as in soil and environmental quality. According to the "Map of potential wind erosion of Hungary" by Lóki (2012), 26.5 % of Hungary is affected strongly or moderately by wind erosion, where the critical threshold velocity of erosive winds is lower than 8.5 m/s. However, this map is based only on a simplified soil texture classification and critical threshold velocity, whereas other factors (wind velocity, land use) were not taken into account. Thus, this map does not provide a full picture of the hazard as it was pointed out by Mezősi et al. (2015). Mezősi et al. (2015) integrated climate, vegetation and soil erodibility factors with fuzzy logic to create wind erosion map of Hungary based on soil texture, climatological and land use data and verified their results by field investigation. The spatial resolution of the databases, they used for representing wind erosion factors, was significantly lower than the inputs of the present approach. Their verification included three test sites and did not contain comprehensive wind erodibility measurements. They took into consideration wind velocity above 9 m/s to represent erosive wind, however this value differs in the case of different soils.

Degradation of land caused by wind erosion strongly depends on the texture of topsoil, therefore mapping of deflation requires the knowledge of soil texture of the uppermost soil layer in proper spatial detail (Borrelli et al. 2014a, Mezősi et al. 2015). Soil texture can be assigned the most accurately by determining particle size distribution (PSD). According to their size, different particles can be categorized as clay, silt, or sand. The size intervals are defined by national or international textural classification systems. Soil textural classes are defined by the numerical proportion (weight percentage) of the sand, silt, and clay separates in the fine-earth fraction (≤ 2 mm). The division is used to be depicted on a triangle diagram, the so-called 'texture triangle'. If the percentage for any two of the soil separates are known, the correct textural class is determined; simultaneously, the sum of the three percentages must total 100 percent. The most commonly used (also in wind erosion models) among the different classification systems is defined by the United States Department of Agriculture (USDA).

The framework of Digital Soil Mapping (DSM; McBratney et al. 2003) involves spatial inference of soil information collected at sampled points based on ancillary environmental variables related to soil forming processes. There are various methods that can be used for establishing quantitative relationships between soil properties and the environment. The recent developments of DSM have significantly extended the potential to predict the spatial distribution of soil properties and related environmental elements more accurately (Lagacherie et al. 2007, Hartemink et al. 2008). The set of the applied DSM techniques has been gradually broadened incorporating and eventually integrating geostatistical, data mining and GIS tools (Minasny et al. 2012). Furthermore the available auxiliary environmental information have been persistently widened. Unique digital soil (related) map products can be compiled that were never mapped before, even nationally with relatively high spatial resolution, taking also into consideration accuracy and reliability (Pásztor et al. 2015).

Our aim was to provide a nationwide, spatially detailed assessment of the susceptibility of the land of Hungary to wind erosion integrating actual and representative wind tunnel measurements, the latest products provided by both digital soil mapping and digital climate characteristic mapping, furthermore the most recent land cover map provided by remote sensing.

Material and methods

Study site

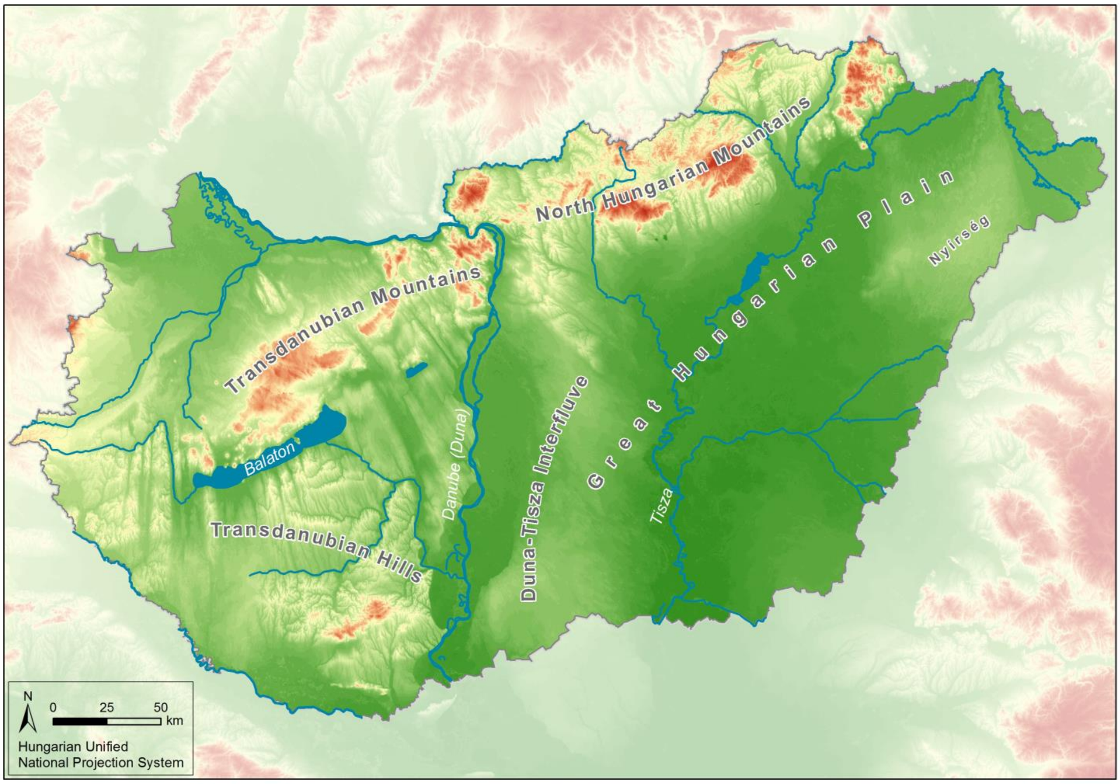

Figure 1. Hungary's general geographical conditions

In Hungary, large areas are covered by sandy and silty soils, which are mainly affected by wind erosion. More than 60% of the relatively flat area is under agriculture cultivation which enlarges the exposure to wind erosion causing serious soil degradation. The mean annual precipitation varies between 500 and 700 mm; the average temperature is 10–11 ºC (1961–1990) (Péczely, 1998). The countrywide yearly average wind speed is 2–4 m/s. The monthly average wind velocity increases continuously in the first months of the year, and the highest monthly average wind velocity can be experienced in March and April (when the agricultural fields are bare). The average wind velocity reaches its maximum in April and number of days on which the maximum wind speed is over 10 m/s is also the highest in this month. The average wind velocity is 3.0–3.2 m/s in the months, which are the most vulnerable to wind erosion (March-April). The main wind direction of winds above 5 m/s is North-Western (on the Transdanubian region) or North-Eastern (on the Great Hungarian Plain). The regional distribution of wind velocity is very variable in Hungary: The strongest winds blow in the Transdanubian region. The number of windy days (when the wind velocity is above 10 m/s) are about 122, and the number of stormy days (when the wind velocity is above 15 m/s) is about 32 days (MET 2016).

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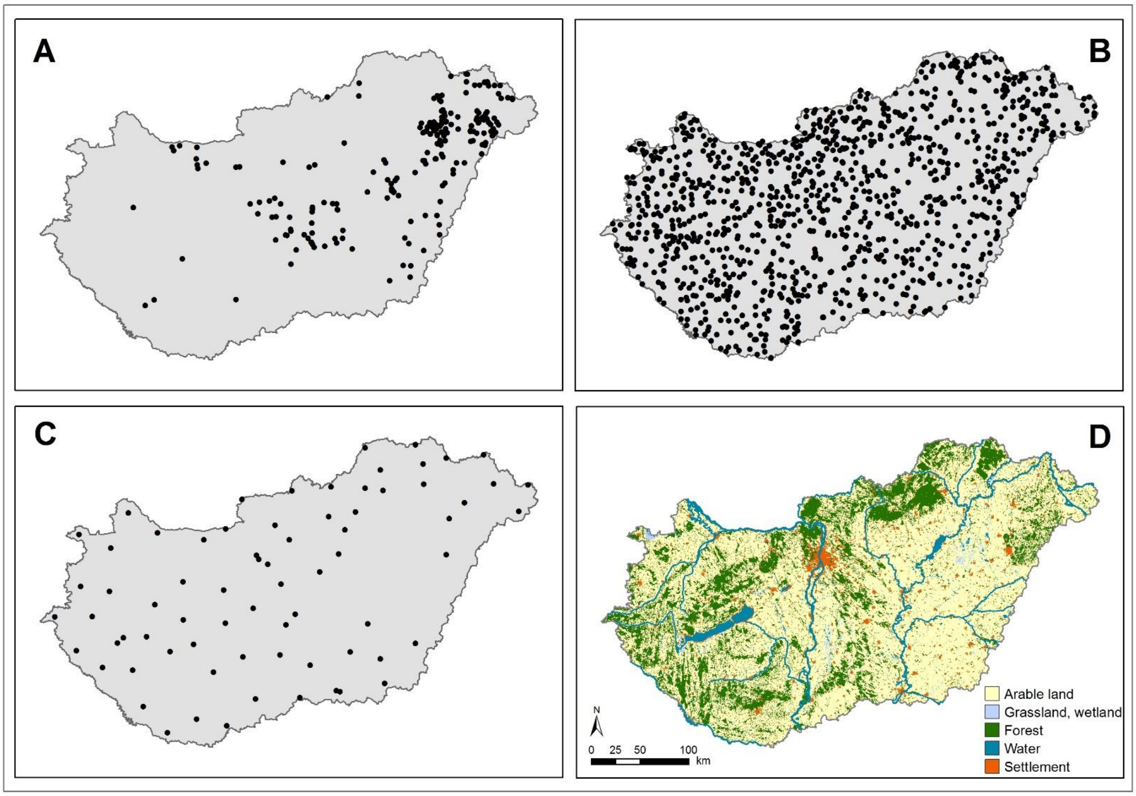

Figure 2. The spatial distribution of sampling points used in the present study: soil sample locations used in wind tunnel measurements (a); SIMS location used in the compilation of soil fractions and texture maps (b); meteorological stations used in long-term wind speed calculations (c); and Hungary's general land cover conditions (d)

Wind tunnel measurement data

The upper 0-20 cm, ploughed layer was sampled at 215 sites collected from different parts of Hungary (Fig. 2a). Soil texture was the primary selection criterion for the assignment of sampling locations. Another important aspect was that each type should be represented by multiple samples; therefore, possible differences between samples belonging to the same texture class became comparable.

Wind tunnel measurements were carried out to determine the erodibility of Hungarian soils with different soil textures. The amount of the transported material by wind was calculated from the weight difference between the samples before and after the experiment. Weight loss was normalized to an erosion modulus (ton hectare-^{1}min^{-1}) to quantify the wind erosion transport rate. Erosion modulus for velocity was calculated by dividing average accumulative soil loss by duration. The applied wind velocity was 16 m/s (which is the maximum wind velocity available in wind tunnel) According to the measured data we created three erodibility categories on the basis of the amount of transported material in an empirical way:

- strongly erodible: 3200 -1500 gram/5 minutes (64 ton hectare-^{1}min^{-1});
- moderately erodible: 1000-1500 gram/5 minutes (30 ton hectare-^{1}min^{-1});
- slightly erodible: 0-1000 gram/5 minutes (20 ton hectare-^{1} min^{-1}).

Threshold wind velocity data were evaluated according to the texture classification of the samples (Table 1), whose result was applied in the parametrization of the countrywide soil texture map compiled for the uppermost (0-5 cm) soil layer.

Table 1. Aggregated threshold wind velocity values by texture classes

Texture	Threshold wind velocity	empirical erodibility classification
loam	9,7 m/s	moderately erodible
silt loam	10,0 m/s	moderately erodible
clay loam	11,0 m/s	slightly erodible
silty clay loam	10,2 m/s	slightly erodible
silty clay	11,5 m/s	slightly erodible
clay	12,0 m/s	slightly erodible
sandy clay loam	9,8 m/s	moderately erodible
sandy loam	8,7 m/s	strongly erodible
loamy sand	7,3 m/s	strongly erodible
sand	6,5 m/s	strongly erodible
sandy clay	10,0 m/s	moderately erodible
silt	10,5 m/s	slightly erodible
organic material	n.a.	non-erodible
water	n.a.	non-erodible
bedrock	n.a.	non-erodible
sealed soil	n.a.	non-erodible

Spatial soil data

Hungarian Soil Information and Monitoring System (SIMS, 1995) contains relevant particle size distribution data on more than 1,200 locations (Fig. 2b). SIMS particle size distribution data were converted into clay, silt and sand particle-size fractions according to the USDA size-groups of mineral particles (USDA 1987; Table 2.; Fig. 3). In SIMS the soil layer related data refer to different depth intervals. For standardization we transformed the soil texture fraction values of each soil profile into standard depth intervals (0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm, 100-200 cm; defined by GlobalSoilMap - ARROUAYS 2014) by equal-area spline interpolation (Bishop et al. 1999; Malone et al. 2009). For the present purpose the deduced values for the topsoil layer (0-5 cm) were used in the subsequent mapping process.

Table 2.

SIMS particle size (mm)	Particle-size fraction
< 0,002	CLAY
0,002-0,005	SILT
0,005-0,01	
0,01-0,02	
0,02-0,05	
0,05-0,2	SAND
0,2-2	

Spatial inference of particle size data was carried out by regression kriging (RK; Hengl et al 2004, 2007), a spatial prediction technique, which uses environmental correlation and geostatistical interpolation as complementary spatial inference methods. It combines the regression of the dependent variable on auxiliary variables with kriging of the regression residuals. RK involves spatially exhaustive, auxiliary information in the mapping process. In the present mapping we used the following environmental covariates.

Topography was taken into account based on the 25 m Digital Elevation Model (EU-DEM 2015) and its morphometric derivatives: Aspect, Channel Network Base Level, Diurnal Anisotropic Heating, Elevation, General Curvature, LS Factor, Mass Balance Index, Multiresolution Index of Ridge Top Flatness – MRRTF, Multiresolution Index of Valley Bottom Flatness – MRVBF, SAGA Wetness Index, Slope, Stream Power Index, Real Surface Area, Topographic Position Index, Topographic Wetness Index and Vertical Distance to Channel Network. The terrain features were calculated from the DEM within SAGA GIS (Bock et al. 2007).

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Lithology was represented by the Geological Map of Hungary 1:100,000 (Gyalog & Síkhegyi 2005). In order to simplify the huge amount of lithology and facies categories, they were correlated with the nomenclature of parent material defined in the FAO Guidelines for soil description (FAO 2006, Bakacsi et al. 2014). Some FAO categories were merged in order to increase the correlation with soil particle size distribution.

Climate was represented by four relevant layers: average annual precipitation, average annual temperature, average annual evaporation and evapotranspiration. The spatial layers were compiled using the MISH method elaborated for the spatial interpolation of surface meteorological elements (Szentimrey & Bihari 2007) based on 30 year observation of the Hungarian Meteorological Service with 0.5' resolution.

Physical **soil** property map contained by the Digital Kreybig Soil Information System (DKSIS, Pásztor et al. 2012) provided further spatial ancillary information (Pásztor et al. 2016). The categories used in legacy maps are defined according to water retention capability, permeability and infiltration rate of soils and they are closely related to the texture classes, however, they cannot be considered identical.

In order to harmonize the different spatial resolution of the predictor variables, we resampled them into a common 100 m grid system (by SAGA GIS - Bock et al. 2007), which also defines the spatial resolution of the result map. All of the auxiliary variables were normalized to a common, 0-255 scale. Category variables were taken apart into indicator variables according to their categories. Every single category has become a layer with a value of 255 while out-of-category areas were coded with 0. Principal component analysis (PCA) was performed on the continuous environmental auxiliary variables and the resulted principal components (PCs) were used in the further procedures. Since PCs are orthogonal and independent, they satisfy the requirements of Multiple Linear Regression Analysis (MLRA) and also decrease multicollinearity.

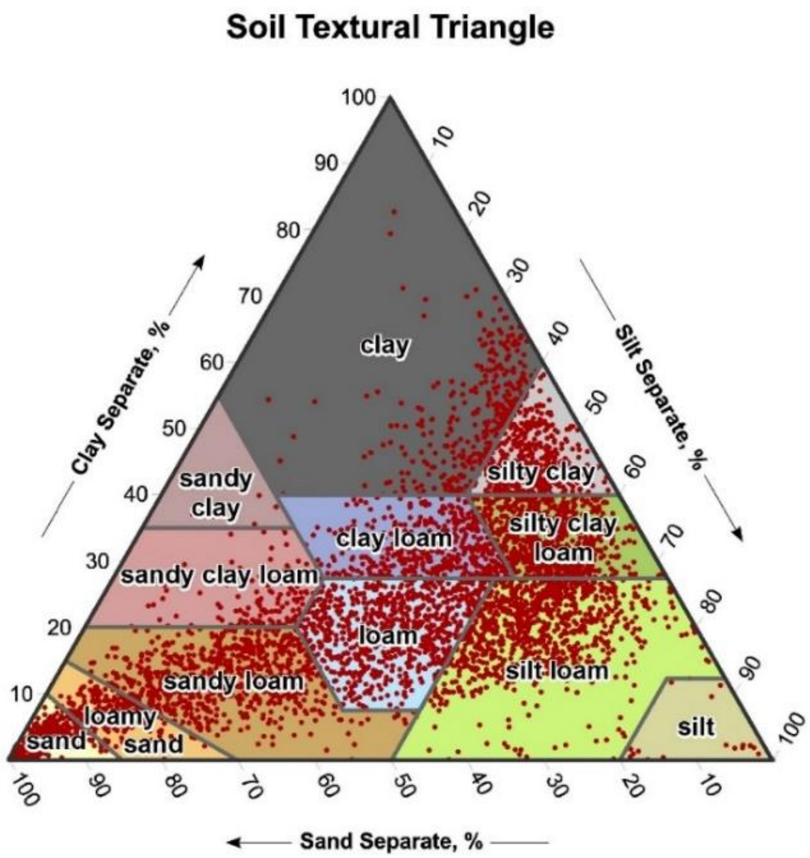

Figure 3. The texture triangle with USDA classification and the distribution of SIMS points

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Since clay, silt and sand contents are compositional variables (their sum must be 100%) instead of inferring the maps independently composite kriging was applied based on Additive Log-Ratio (alr) transformation (Aitchison 1986, Lark & Bishop 2007, Ballabio et al. 2016) of the original three variables. The texture class map itself was compiled according to the USDA categories based on the proper pixel by pixel combination of the three particle size distribution maps. Certain areas (like organic or sealed soil, outcrops and water) cannot be featured by soil texture, so the map treats them independently without providing spatial prediction to them. The compiled map is displayed in Fig. 4.

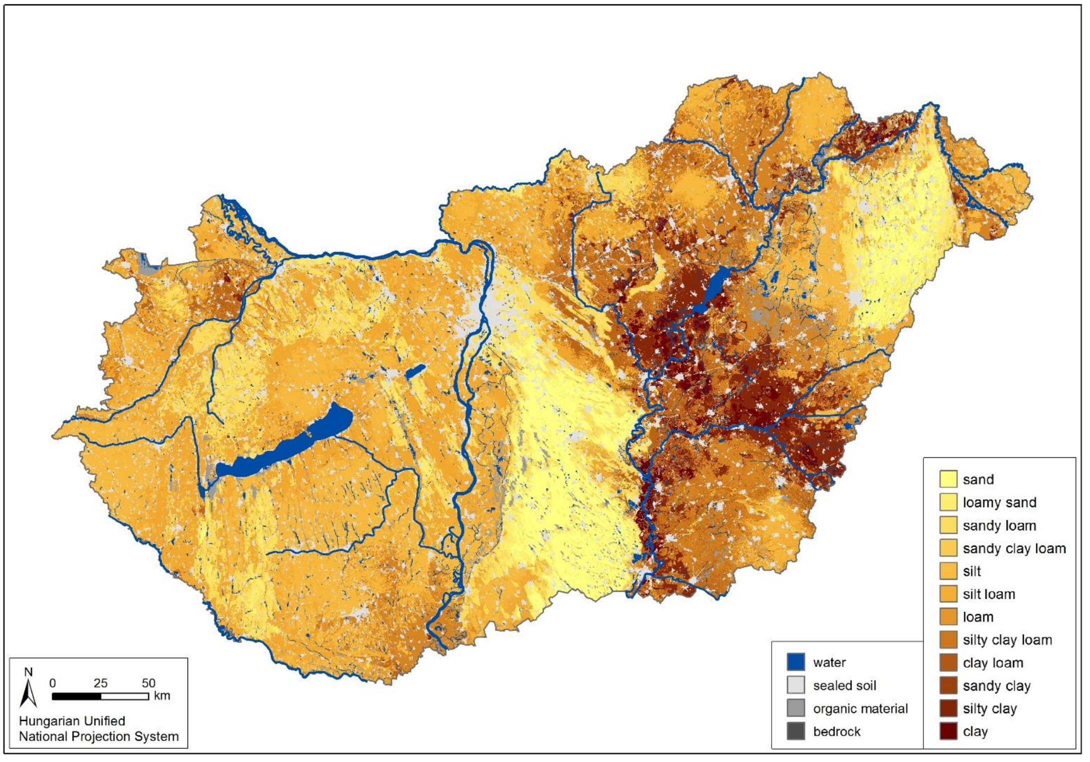

Figure 4. Hungary’s soil texture map of the uppermost layer (0-5 cm) according to the USDA categorization

Wind speed data and its spatial inference

Wind speed data were provided and processed by the Hungarian Meteorological Service. The aim was to determine how frequently wind speed exceeds a certain critical speed value in each grid point of a dense, 0.5′ spatial resolution grid. In order to ensure highest quality of background data several regards were taken into consideration. Before the ‘90s the Service operated manned synoptic stations that measured wind speed in a different manner than in recent years. At most stations wind speed was observed only in every 3 or 6 hours, and only a limited number of stations were equipped with anemographs. By the year 2000 almost all stations had received new, automatic instruments capable of continuous measurements, therefore the decision was to use hourly average wind speed data starting from 2000 through 2013. Selection criteria for stations were that the number of missing data should not exceed 10% (out of thirteen years’ 113,952 entry of hourly data) in the station’s dataset. Altogether 72 stations (Fig. 2d) met these requirements.
The next step was to produce values on a dense grid covering the area of Hungary. This was carried out by applying the MISH (Meteorological Interpolation based on Surface Homogenized Data Basis, *Szentimrey and Bihari*, 2004) method for gridding of hourly station data. It was developed at the Hungarian Meteorological Service specifically for the interpolation of meteorological data, and is based on the idea that the highest quality interpolation formula can be obtained when certain statistical parameters are known. These parameters are

derived by modelling, using long term homogenized data of neighboring stations. The MISHv1.03 software first carries out the modelling of statistical parameters, using additional variables such as topography, height of measurement, or roughness length. The interpolation itself is achieved in the second step, using an interpolation formula that depends on the output of the modelling system. Therefore the obtained value of a grid point is determined not only by the values of the actual time step, but the long term climatic data of the neighboring stations as well.

Due to the immense computation demand of gridding, the MISH method limits the number of predictor series to 2,000, the length of series to 4,000 and the predictand locations to 10,000. The predictor series were the 72 station series, but speaking of hourly data they had much more than 4,000 values each and the predictands of a 0.5´grid were much more than the limit as well. The problem of the length of series was overcome by splitting the series to fragments: gridding of hourly data was done separately for each month; moreover each month's data were split into three parts to fit the 4,000 limit of length. In order to meet the limit of predictand locations the grid had to be truncated. Considering that the spatial variance of wind speed is much less above flat terrain an iteration formula was developed to determine the best grid network that has at most 10,000 grid points, but is preferably denser around mountainous regions. The fragments were all gridded onto this somewhat irregular grid of 9,984 predictand points and then finally merged together into one file. The dense, 0.5´ resolution grid was then matched with the 9,984 predictand values in the manner of finding the closest predictand point to each point of the dense grid, thus values of each point were ultimately acquired.

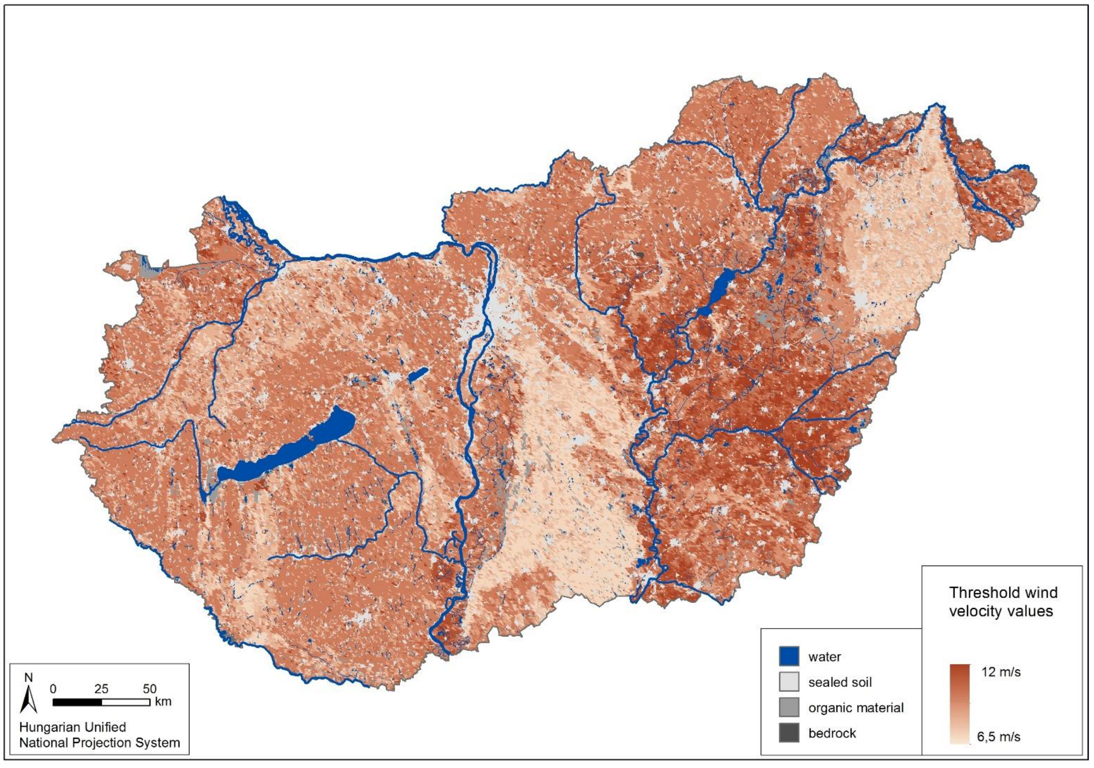

Figure 5. Threshold wind velocity values linked to the centers of the 0.5´ resolution grid based on the soil texture map

Land cover

CORINE Land Cover 1:50.000 (CLC50; Büttner et al. 2004) was used for representing the role of landuse/landcover in modelling the exposure of land to wind erosion. CLC50 is a national land cover database elaborated on the basis of the CORINE nomenclature of the European Environment Agency (EEA) and adapted to fit the characteristics of Hungary. However, CLC 50 is not the most recent version of Corine databases, but its spatial resolution is significantly finer, being the smallest delineated unit is 4 hectare and 1 hectare in the case of water bodies.

According to CLC50 about 56% of Hungary is under agricultural cultivation while about 44% of the country's area is featured by land characteristics, which are more resistant to wind erosion. Since wind erosion does not typically occur in forests, urbanized areas and over water surface, consequently these areas were masked out.

Results and discussion

Critical wind speed exceedance map

The outcome of wind speed exceedance calculations was the ratio of wind speed exceeding critical values on an hourly level during the observed 13 years in each point of the grid network (Fig. 5). According to the map, spatial variability is relatively high throughout the country. Values in general range from 0% to above 2.5% in relation to wind climatology, landscape, soil properties and land cover.

Most of Hungary has values smaller than 0.5%; moreover, a significant portion of the country presents ratios that do not exceed 0.01%. These regions, in particular the western borderline, most of the North Hungarian Mountains (the subsequently mentioned geographical names are displayed in Fig. 1), Southern Transdanubia and several patches scattered across the Great Plain are characterized by wind speeds virtually never reaching critical values. Ratios up to 0.5% appear to be predominant in areas east of the Danube excluding two major territories: most of the plain between the Danube and Tisza rivers, and the Nyírség in Northern Great Plain, close to the north-eastern corner of the country. Wind speeds exceeding critical values are somewhat more prevalent in these regions, but ratios higher than 2% are still exceptionally rare. In the western half of Hungary, however, we can find more outstanding values. Around the Lake Balaton, especially in the Transdanubian Mountains values higher than 1% are relatively common, and several smaller areas present ratios higher than 2.5%, indicating a significantly higher probability of critical wind stress.

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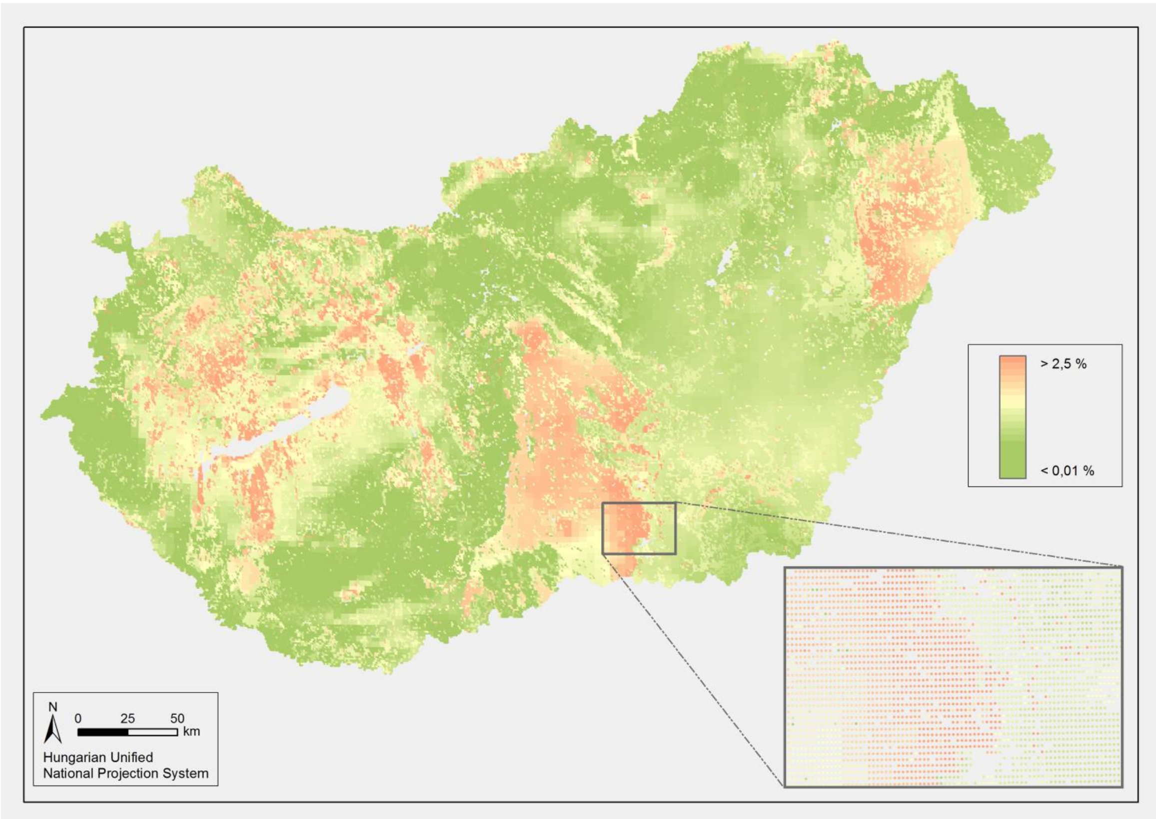

Figure. 6. Ratio of hourly wind speed exceeding critical values (2000-2013) calculated for the 0.5´ resolution grid points

Wind erosion susceptibility map

The ratio of hourly wind speed exceeding critical value can already be considered as a proper indicator of wind erosion susceptibility. However basically, these values were inferred for the applied 0.5´ spatial resolution grid, which cannot be actually considered as a real map. To create a spatially exhaustive map, the calculated values were further interpolated using co-kriging to a 1 ha spatial resolution grid. Sand and silt content of the uppermost (0-5 cm) soil layer, formerly used for the compilation of the reference soil texture map, were used as appropriate numerical co-variables. The final map (Fig.7) was produced by masking out areas, which cannot be exposed to wind erosion due to their land use/land cover characteristic.

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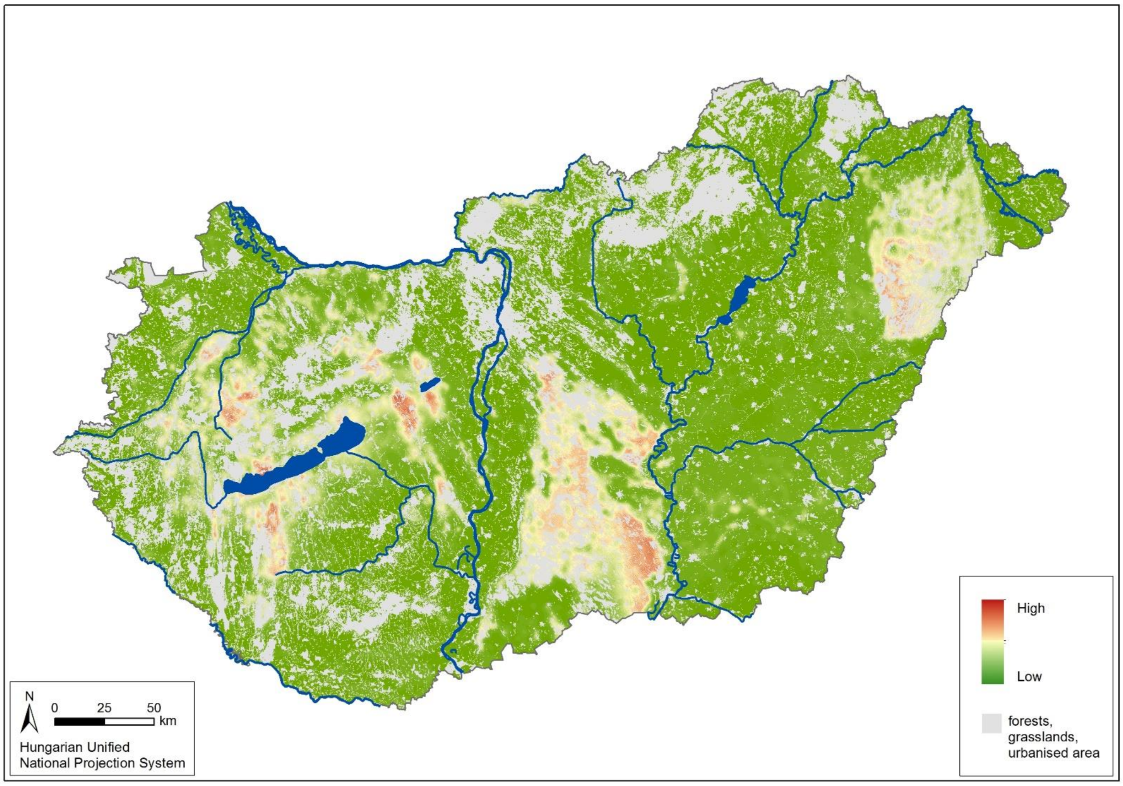

Fig 7 Wind erosion susceptibility map of the Hungarian soils

According to the compiled maps roughly 10% of the country is affected by higher risk of wind erosion. This is the consequence mainly of the vegetation cover and only secondly the occurrence of erosive winds, that is wind with velocity exceeding the local critical threshold value. In the majority of the country the winds do not exceed the critical velocity during the year, so albeit the soil and landuse/landcover conditions would cause, wind erosion harm occur very rarely. It can be expected merely in the case of strong cold fronts. In generally arable lands situated on lowlands and covered by sandy soils are the most endangered by wind erosion, because they are featured by relatively small critical threshold velocity (6-7 m/s), consequently winds having even gentle energy are capable to transport the upper soil layer.

The fine continuous scale of the wind erosion susceptibility map together with its high spatial resolution is not necessarily applicable for decision making in land management and spatial planning. Consequently, we created a simplified version of the map (Fig.8). We classified the ratio of hourly wind speed exceeding critical value into three categories based on statistical properties of its distribution, which was supplemented with a fourth category of non-erodible areas according to CLC50.

According to the categorized map five distinct territories can be identified in the country with typically higher wind erosion risk:

1. The Nyírség is an ancient alluvial fan, its area is about 5,100 km^2 and consists of mainly sandy soils and its different variant. About one third part of the area are covered by forests (mainly the eolian forms), but there is difference in this regard in regional distribution, because territories covered by sandy loam, loam and silty loam are under agricultural cultivation and are more endangered by wind erosion.

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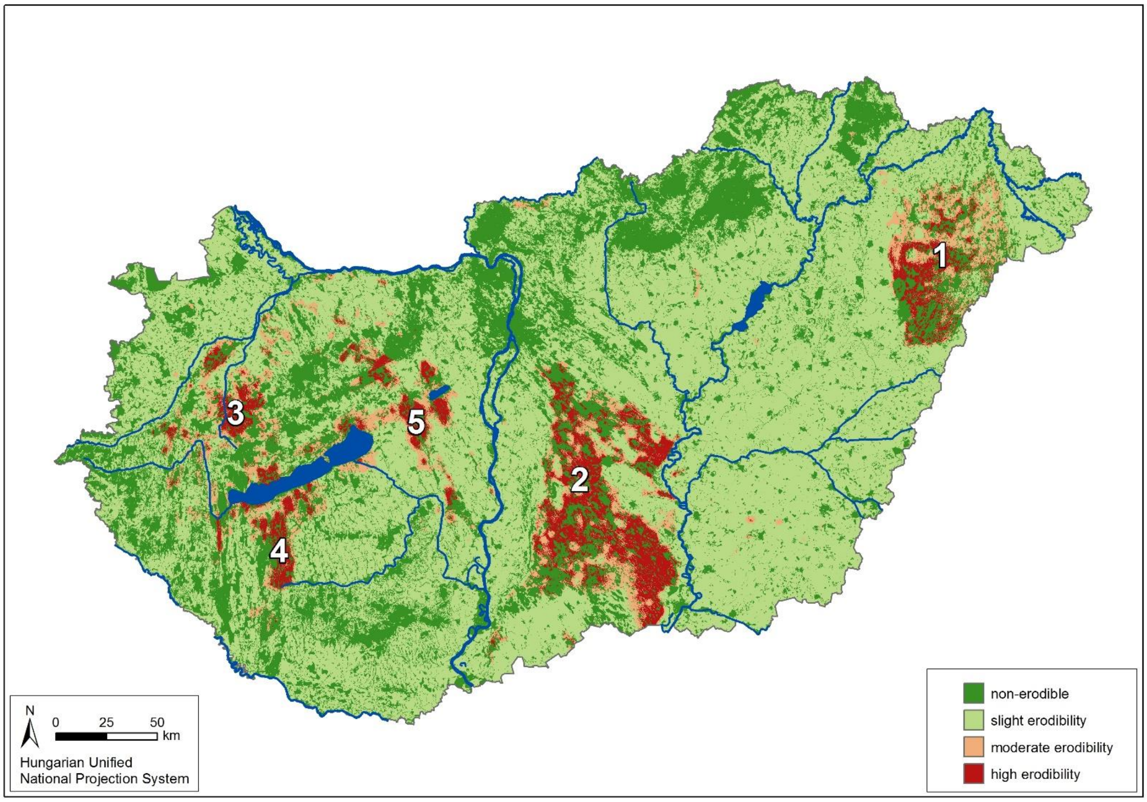

Fig 8 Categorized wind erosion susceptibility map of the Hungarian soils. The five distinct areas with typically higher wind erosion risk are numbered: Nyírség (1), Duna-Tisza Interfluve (2), glacis in the foreground of the Transdanubian Mountains (3), Inner-Somogy (4), Transdanubian loess region (5).

2. The Duna-Tisza Interfluve is about 10,000 km^2 and also consists of sandy soils and its variant. A significant discrepancy to the Nyírség that this area is poorer in precipitation (500-550 mm) and there are drought periods in many years. As a consequence of its dryer climate, its forest cover is sparser than in Nyírség.
3. The glacis in the foreground of the Transdanubian Mountains are affected by wind erosion because of mainly two reasons. In one hand they are covered by sandy soils, on the other hand the wind velocity is the highest in Hungary – because this region is exposed perpendicularly to the dominant winds blowing from northwest.
4. The Inner-Somogy is about 3,000 km^2. However, it has more precipitation, than Nyírség and Duna-Tisza Interfluve, according to the alluvial fan origin of the area, it is also covered by sandy soils, which make it more endangered by wind erosion.
5. The Transdanubian loess region is also situated in the Transdanubian region and consists of loess. The productivity of the soils formed on them is outstanding, so the dominant landuse is arable lands. This territory is also exposed perpendicularly to the winds blowing from northwest, which together with the seasonally uncovered and extended agricultural areas make it more susceptible to wind erosion.

Conclusions

Comparing our results to those of others (Boreli at all. 2014, Funk and Reuter, 2006) we can conclude that – however the methods applied by us was different - the regional distribution of areas featured by higher risk of wind erosion is in good agreement with our results. Table 4. compares the extent of wind-susceptible areas in Hungary according to our categorization with that of inferred by Borelli et al. (2014). In spite of the generic methodological differences the figures are quite similar. Stefanovits and Várallyay (1992) evaluated the extent of wind erosion based on the costs payed out by insurance companies for wind erosion harms and their results coincide very well with our findings. Mezősi et al. (2015), also got into similar results based on less detailed input data. The main pattern of former approaches is reflected with reliable accuracy, nevertheless the recent map can be considered as a specific zooming in into the spatial behavior of wind erosion due to the application of significantly more detailed input data.

Table 4. The extent of wind-susceptible areas in Hungary

	Spatial distribution based on wind tunnel measurements		**Spatial distribution based on Borelli's data**	
Erodibility categories	**Area (km^2)**	**Percentage (%)**	**Area (km^2)**	**Percentage (%)**
non-erodible	29052,0	31,2	41707,5	44,8
slight erodibility	54436,0	58,5	46375,0	49,8
moderate erodibility	5208,0	5,6	4384,6	4,7
high erodibility	4333,0	4,7	562,9	0,6
Total	93030,0	100,0	93030,0	100,0

The applied climatic parameter, namely ratio of hourly wind speed exceeding critical values, proved to be a fairly well applicable indicator for the characterization and mapping of wind erosion risk. The comparison of this parameter with other ones, which are used for the description of wind features (number of stormy days, number of days with winds over a critical threshold etc.) could be a potential further step. Nevertheless we consider the present parameter fully informative, since it takes into consideration also the duration of the winds exceeding the critical threshold values.

We would like to emphasize that the derived wind erosion map displays the current, actually static state. The wind erosion causing and affecting factors (like landcover/landuse, soil moisture content, management technology) vary both spatially and temporally. Beside soil moisture content, the applied management technology plays important role, since the structure of soils even with identical texture category may be differently damaged due to improper management techniques. Information on this factor could be collected by field observations and/or large scale mapping. But detailed and timely data are not currently available and even cannot be expected in the near future, which could be used for nationwide mapping. A suitable solution could be the proper implication of these factors into process models and scenario based runs of the developed models.

We see some further possibilities for the improvement of the presented approach. It would be a major step forward to functionally relate the resistance of soils to wind erosion with their erodibility factor (EF), which can be calculated from basic soil properties (sand, silt, clay, organic matter and carbonate content) instead of leaning on texture classes. In this case critical threshold values could be estimated directly by EF and also indirectly by widely used soil data. Since nationwide soil property maps of these parameters have been very recently compiled, they could support a new approximation for mapping wind erosion susceptibility on national level. Eliminating the application of class averages the expected accuracy of both thematic and spatial prediction is suggested to be improved.

Nevertheless the complied map in its present form provides solid basis for the regional characterization of wind erosion risk, consequently for the planning of protection against it and finally for a rational distribution of subsidies supporting the protection.

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