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ESTIMATION OF SOIL EROSION RISK AREAS BY GIS ANALYSIS OF LAND USE AND SOIL MAPS: AN ESTONIAN CASE STUDY

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Abstract: Land use in areas prone to soil erosion processes is one of the most important parameters for evaluating the risk of water and wind erosion. Therefore the estimation of the proportion and location of arable land and permanent (including natural) grasslands in erosion sensitive areas by land use databases, the Estonian soil map and orthophotographs were the goals of the current research. We used the Estonian large scale digital soil map (1:10,000) for estimating areas at risk of wind erosion. We selected fields with a sandy texture over 3 ha and fields of peat soils over 0.5 ha in size in areas with higher wind speeds, mainly in coastal and lakeshore counties. The Estonian soil map identifies three subgroups of soils vulnerable to water erosion. GIS queries and analyses of the Estonian soil map in conjunction with data from ARIB (Agricultural Registers and Information Board) indicated that soils vulnerable to water erosion exist on 40,000 ha of ARIB registered land, of which 16,000 ha is arable land. Although this finding means 40% of agricultural land is at risk from water erosion, the proportion of arable land varies considerably from one county to another (27-54%). The use of water erodible soils for arable land is greater in counties, in which intensity of erosion is low and the proportion of erodible soils is fairly small. Estimates, based on the GIS queries, indicated that wind erodible soils comprised approximately 100,000 ha of Estonia's agricultural land, of which about 32% are high wind erosion risk arable fields. The Universal Soil Loss Equation model enabled us to estimate the average soil erosion intensity of fields covered by natural vegetation as a low rate of 0.04 t ha^{-1} y^{-1}, even in the high risk areas (i.e counties where the eroded soils are wide spread). However, changes in land use from natural vegetation to intensively managed arable land accelerate the intensity of soil erosion to 0.43 t ha^{-1} y^{-1}.
Key Words: Water erosion, Wind erosion, GIS, Land use

1. INTRODUCTION

The displacement agents of soil, particles or mass, are water, wind and human activity and water, wind and tillage erosion are distinguishable. All three erosion types are present in Estonia. The wind erosion mostly occurs in areas open to wind activity but causes less damage than water erosion (Ratas, Int, 1978). The wind carries away soil particles when there is no vegetation ground cover, the soil is dry and tillage was recent. Wind erosion has not been recorded as occurring in soil covered by vegetation (Kask, 1996). Field trials have revealed that under the same parameters of precipitation and soil type, the vegetation type influences the intensity of erosion. Inter-tilled crops intensify the erosion process more than either grassland or forest vegetation (Kirkby, Morgan, 1984). The occurrence of eroded soils, in Estonia, and the intensity of erosion are fairly low level as the majority of the country has a flattened topography with undulating plains and small hills. Nevertheless, there are the regions where water eroded soils are wide spread, especially in southern Estonia's hilly ground moraine areas (Reintam et al, 2000). The factors preventing widespread wind erosion are (i) the high proportion of land covered by forestry (50.6% of Estonia's territory (Yearbook Forest 2008)) and (ii) the mosaic agricultural landscape of small size (7.2 ha according to the ARIB land parcels register, 2010) fields. The most serious wind erosion occurs in coastal areas on sandy and peat soils.

Soil erosion mainly accompanies crop agricultural (arable) land use and specifically soil tillage, but until recently land use data has not been accurate enough to enable GIS queries from the Estonian soil map. The goal of the study was to discover the location and land usage of erosion vulnerable soils. The strategy was to draw up potential risk areas of erosion, arable crop rotation land. This strategy provides the opportunity to identify the risk areas at the parish (Parish in Estonia is the smallest administrative unit) level and, if necessary, at field level according to the spread of arable land and long-term grasslands in agricultural use. Annually updated the land use data would enable regular monitoring of the changes in risk areas of erosion.

2. MATERIAL AND METHODS

2.1. Water Erosion

The distribution contours of soils affected by water erosion and generalized data are available on the large scale (1:10 000) Estonia soil map (ESM) (Estonian Land Board, 2010). Water eroded soils are mainly concentrated in southern Estonia (Figure 1).

We initially used the 2008 databases of Estonia's Agricultural Registers and Information Board (ARIB) to identify the land usage of the risk areas for water erosion. Secondly, we used ESM to locate and map water eroded soil types, and penultimately we employed GIS queries and analyses to discover the land use on these soils. Finally with the aid of orthophotographs we were able to specify the proportion of natural and long term (cultural) grasslands and arable land (Figure 2).

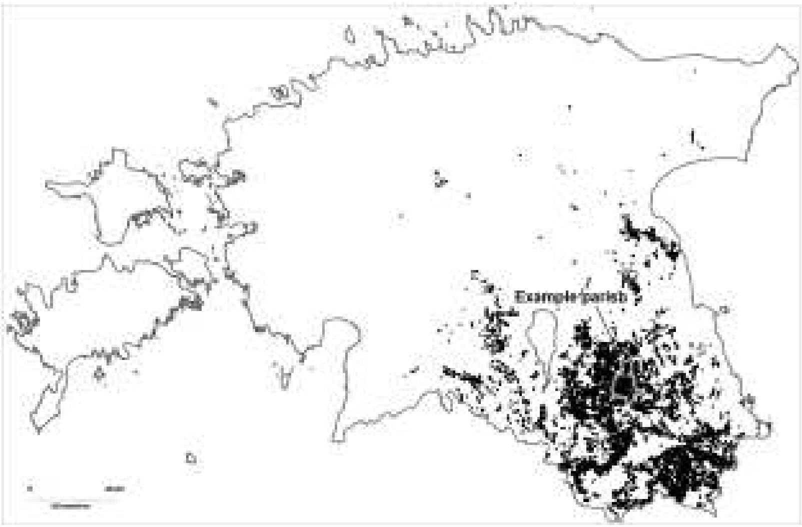

Figure 1. Distribution of water eroded soils according to the digital soil map of Estonia and the location of the parish of Valgjärve used for assessing the area of arable land on eroded soils as the higher risk areas for erosion

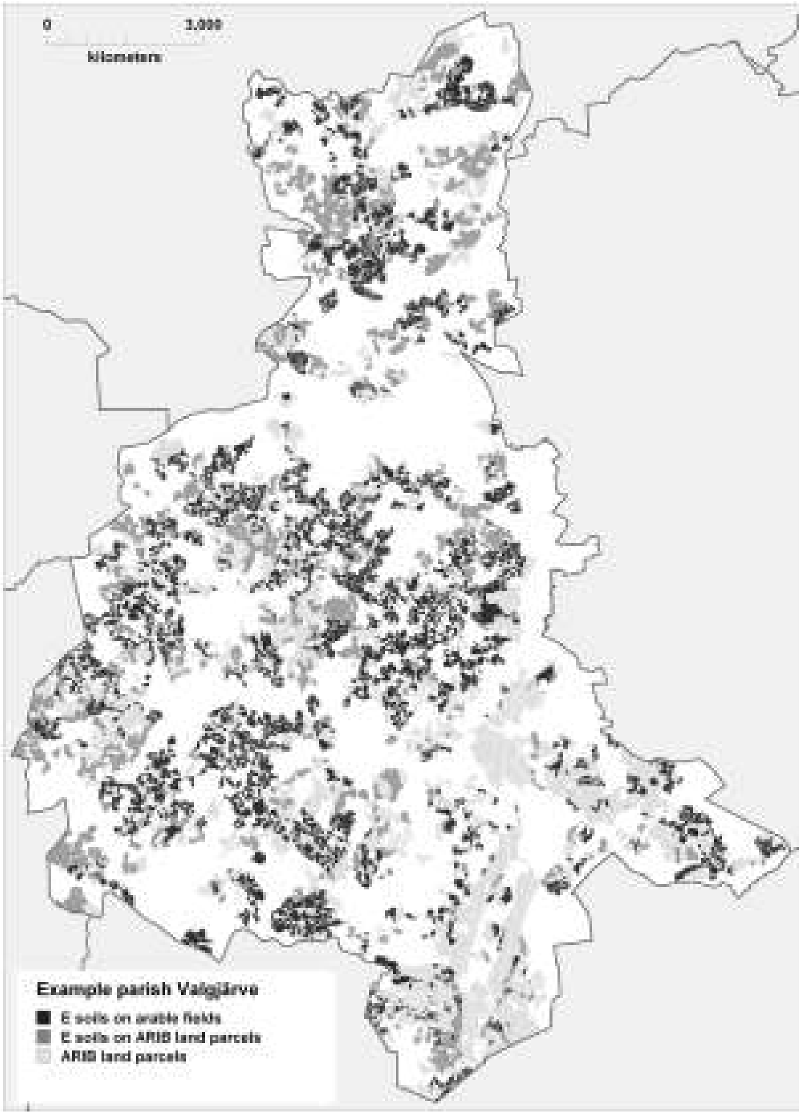

Figure 2. The parish of Valgjärve indicating the location of arable fields in water eroded soils using data from Estonia's soil map, ARIB databases (2008), orphotographs and GIS analysis

2.2. Wind Erosion

We used the ESM to assess the risk areas for wind erosion. We selected sand based fields greater than 3 ha and peat based fields greater than 0.5 ha in the coastal zone and on the shores of the biggest lakes (Pepsi and Võrtsjärv). The intensity and regularity of wind speed is higher in coastal and lakeshore zones than inland areas (Kull, 1999). In order to assess the water erosion risk areas we used a similar methodology to the study of wind erosion risk areas except we used ARIB's 2009 databases.

3. RESULTS AND DISCUSSION

3.1. Assessing the Land Use on Wind Erosion Risk Area

Wind speed and the tillage condition of land determine the intensity and extent of wind erosion (Kask, 1996). Wind erosion occurs under a complex of conditions such as fairly high wind speed, low air humidity (less than 30-60%), dry soil and a large open field. These conditions usually exist at the beginning of the vegetation period when large arable fields are without the vegetation cover. The majority of annual wind erosion damage (80%) occurs in April and May (Ratas, Int, 1978).

Soil texture is also a highly important factor influencing location-specific wind erosion. Light textures (e.g. sand and sandy loam) have low water capacities and high levels of water permeability, so that precipitation goes rapidly through the soil profile causing the soil to dry equally quickly. This aspect makes light textured soils susceptible to the wind erosion. Ratas (1977) evaluated the risk assessments of wind erosion of agricultural land in Estonia's coastal area are moderate risk for 18% (56858 ha) and severe for 21% (66334 ha).

Land use data queries of ARIB 2009 of the aggregate area of arable land on wind erosion susceptible soils indicated that four parishes had substantial areas of land (more than 1000 ha) that were potentially prone to erosion (Figure 3).

The GIS analyses and queries of the ARIB land use database indicated that in windy areas (coastal and lakeshores) the ratio of soil by area (ha) to arable land use by area (ha) was 54, 298:17,562 (32.5%) for sandy soils and 49,875:16,313 (32.7%) for peat soils. The total area of wind erosion vulnerable soils measures 104 173 ha, of which 33875 ha (32%) is arable land and therefore at higher risk of wind erosion. The area at risk to wind erosion is larger than the area at risk of water erosion, but during field work we found out that the damage caused by wind erosion is less significant than water erosion.

3.2. Land Use on Water Erosion Risk Area

The risk of soil erosion on sloping ground depends mostly on land usage as permanent vegetation, despite the angle of inclination, minimizes the erosion; nevertheless intensive tillage on almost horizontal slopes can cause a dramatic relocation of soil mass through water erosion (Kõlli et al, 2009). Research has also indicated the removal of natural vegetation from steep slopes, in order to provide arable land, can cause the intense erosion process known as gullying (Sepp et al, 2006). The incidence of water eroded soils, including eroded and deluvial soil complexes, comprised 2.1% of Estonia's land, 0.1% of forested areas but 5.5% of arable land (Kokk et al. 1991).

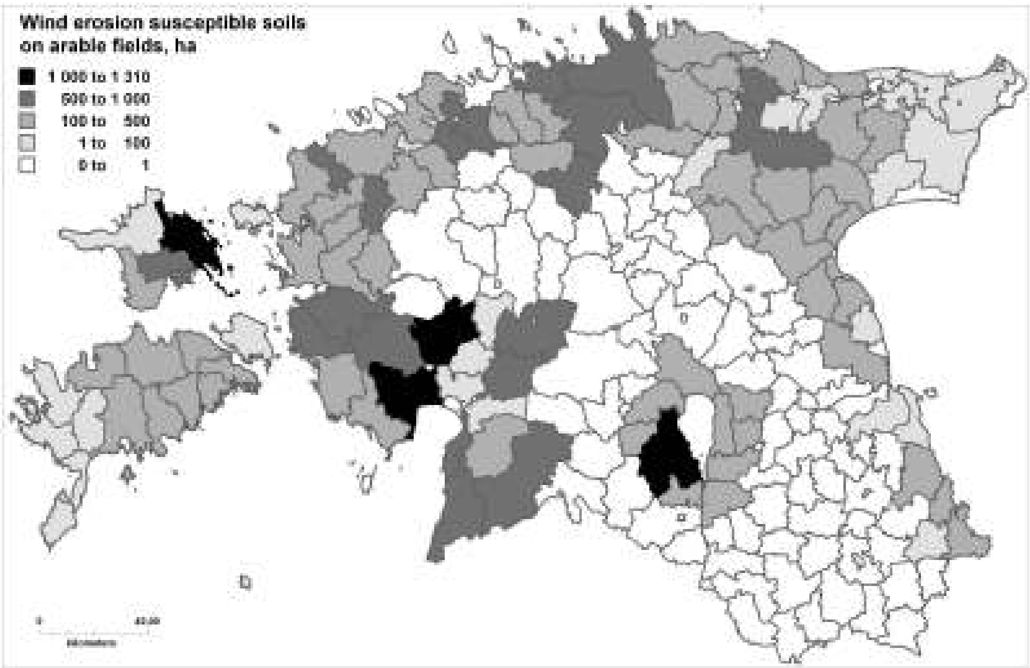

Figure3. Wind erosion susceptible soils on arable fields by the parishes of Estonia

The annual average intensity of soil loss, by water erosion, estimated by Universal Soil Loss Equation (USLE) model for water erosion sensitive areas, in Põlva and Võru counties, was 0.016-0.04 t ha^{-1} for natural grassland. By intensively managed arable land the rate of soil loss by water erosion increased remarkably reaching from 0.22 t ha^{-1} till 0.43 t ha^{-1} in these counties, respectively. The annual aggregate loss of soil on arable land of these two counties was 11,110 t for Põlva county and 15,287 t for Võru county (Kull, Kull 2010).

Our research of ARIB's 2008 land use data revealed fields on water eroded soils, as per the ESM, formed approximately 40 000 ha mostly in south-eastern Estonia, of which 40% is arable land (Figure 4). Two adjacent parishes each have more than 1000 ha eroded soils on arable land, which equates to 54-68% of eroded soils in ARIB land use for these two parishes.

Soils at high risk of water erosion are concentrated in the four southern counties, Tartu, Põlva, Võru and Valga. An average of 12% land in ARIB's database is situated on eroded soils in these four counties. The proportion of water eroded soils on ARIB registered agricultural land is highest (17-18%) in Võru and Valga counties where the prevailing land usage is natural and long term grasslands, which have a low incidence of erosion, and the proportional use of eroded soils as arable land is 27-39% (Figure 5). Usage of eroded soils for arable land is usually greater in counties where the degree of erosion and proportion of eroded soils is relatively smaller.

In 2004, the Estonian Agri-Environmental Programme started several measures, which should mitigate the problem of wind and water soil erosion. The study of land use in erosion vulnerable areas revealed that a large proportion of the agricultural land is under the permanent grassland (long-term cultivated grasslands and natural grasslands) and the area occupying erosion susceptible soils in arable use is less than 6% of all agricultural land registered in ARIB databases. Therefore the implementation of erosion preventative measures that would embrace the entire agricultural land area of Estonia was not topical. However, there are parishes where substantial areas have both a high proportion of soils vulnerable to erosion and a high proportion of these erosion vulnerable soils are under the arable land (18%).

The current research enables land management to locate any area under the arable land in erosion sensitive areas at both the parish and field level. This in turn enables land management to implement preventative measures, (e.g. using minimal tillage or direct sowing, winter crop cover, leaving standing stubble on the field, and establishing permanent grasslands) to minimize or slow down soil erosion loss. The state could also subsidize farmers willing to adopt these preventative measures. Indeed, since 2009, the state implemented a policy concerning winter crop cover, which requires that at least 30% of the agricultural land would be covered during the winter in the five parishes possessing the most erosion susceptible soils.

4. CONCLUSION

GIS analyses of land use on soil erosion vulnerable areas in Estonia indicate that 40% of water erosion vulnerable soils and 32% of wind erosion vulnerable soils among ARIB land parcels are used for intensive arable management. The aggregate of these land parcels equates to approximately 6% of the total agricultural land in ARIB register.

The results of the current research provide an opportunity to introduce erosion risk areas at parish and also field levels specifically for the spreading of arable land and long-term grasslands in agricultural use. The results also provide the opportunity to decide the implementation and financing of special preventative soil erosion measures at state level.

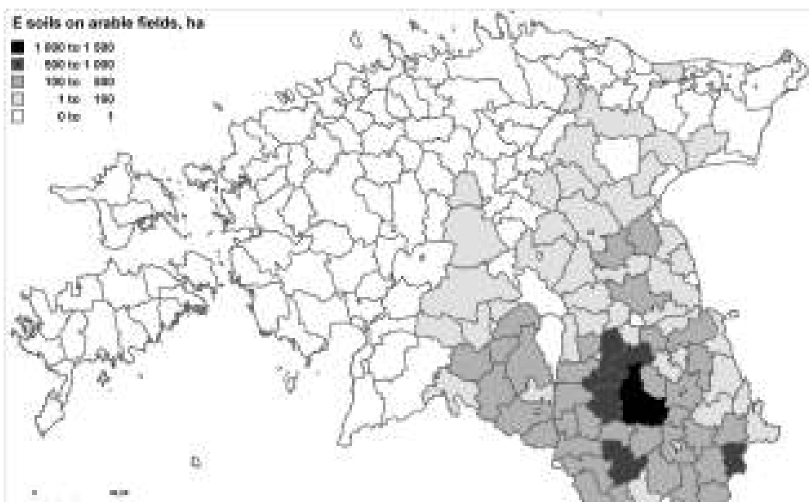

Figure 4. Water eroded soils on arable fields by parishes, in Estonia, based on Estonian Soil Map and ARIB land usage data (E soils - erodible soils)

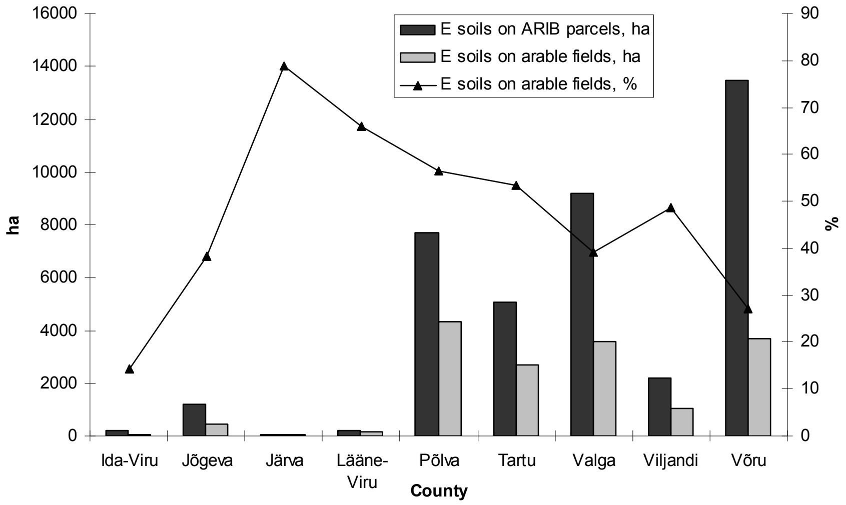

Figure 5. Water eroded soils by area and proportion on ARIB parcels and arable fields in the counties of Estonia (E soils – erodible soils)

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