ASSESSING OIL RETENTION MAP WITH PEDOTRASFER FUCTIONS FOR A STUDY AREA AT KESZTHELY, HUNGARY

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Abstract

Oil spills are among the most common sources of soil pollution therefore, it is necessary to spatially assess the sensitivity of soils. Our goal was to develop a method which is suitable for such assessment. Oil retention at various pressures was determined in an earlier study and it was found that soil organic matter and sand content determine the oil retention at one bar. However, regular soil tests in Hungary do not include particle size distribution measurements hence sand content only liquid limit according to Arany is determined and generally, spatial density of recent soil tests is insufficient to perform spatial assessment. We have developed a method to estimate the most probable particle size percentages based on regular measurements and we used all available high resolution soil legacy data to derive spatial estimates of sand and organic matter content for a study area at Keszthely, Hungary. From these base maps, oil retention of the upper soil layer at one bar pressure was assessed. Because of the averaging nature of the used statistical methods (regression analysis, kriging) the values around the average (19.1 vol %) were frequent in the estimated map but large or small values which were present among the data used to develop the estimating equation were generally missing.

Keywords: oil retention, pedotransfer functions, digital soil mapping methods, liquid limit according to Arany

Összefoglalás

A talajok olajszennyezése a leggyakoribb talajszennyezések egyike. Bármely talaj, amelyet érint az emberi tevékenység és a robbanómotorok használata, ki van téve ennek a kockázatnak valamilyen mértékben, ezért fontos, hogy a talajok érzékenységét térképszerűen becsülni tudjuk. Célunk volt, hogy kifejlesszünk egy erre alkalmas becslési módszert. A talajok olajvisszatartó képességét egy korábbi kutatás során vizsgáltuk különböző nyomásokon, és megállapítottuk, hogy egy bár nyomáson a szerves anyag tartalom és a homoktartalom a legfontosabb befolyásoló tényezők. Azonban a szokásos talajvizsgálatok során Magyarországon nem határozzák meg a talajok szemcseméret összetételét, így homoktartalmát sem, csak az Arany-féle kötöttségi számot mérik. Továbbá a jelenlegi talajvizsgálatok térbeli sűrűsége sem elég nagy ahhoz, hogy azokból térbeli becslést lehessen végezni. Kifejlesztettünk egy módszert, amellyel a szokásos talajvizsgálati adatokból meghatározhatók a legvalószínűbb szemcseméret eloszlás arányok, és a múltbéli összes elérhető talajvizsgálati adatot felhasználva becslést készítettünk egy Keszthely melletti mintaterületre a talaj szerves anyag és homoktartalmára vonatkozóan. Ezekből az alaptérképekből kiindulva becsültük a talaj felső rétegének olajvisszatartó képességét egy bár nyomáson. Az alkalmazott módszerek átlagoló tulajdonság amiatt (regresszió analízis, kriging) az átlag körüli értékek (19.1 térfogat %) gyakoriak voltak a becsült térképen, de hiányoztak a

szélsőségesen nagy és kis értékek, amelyek pedig a becslőegyenlet kifejlesztéséhez használt adatbázisban szerepeltek.

Introduction

About 20 million tons of oil and petroleum products are used world wide each day. In Canada, 12 spills of more than 4000 L are reported each day while in the United States, 85 of such spills occur daily on land (Fingas, 2013). Expectedly, several hundreds of small spills occur each day in all countries most of them on land therefore, assessment of sensitivity of soils to this kind of pollution may have large environmental significance. The risk of oil spills in the vicinity of various activities may be vastly different. The probability of larger accidents is much higher along the major transportation lines (pipelines, highways, railways) but systematic spatial assessment of soil sensitivity is not known in Hungary for soils along these lines.

There is a general soil map for Hungary that enables to design policies at large scale (Várallyay et al., 1979, 1980) but detailed soil maps are missing to support fine scale intervention. Hungary is rich in legacy soil data and there are two soil maps and two thematic databases that can be used as potential sources to compile an updated and detailed soil map. However, systematic evaluation of the sources is largely missing (Sisák and Bámer, 2008) in spite of the fact that both Hungarian Soil Protection Strategy (Németh et al., 2005) and EU INSPIRE Directive (EC, 2007) require. Detailed sources are still partially digitized (Pásztor et al., 2010), or they are only in the initial phase of harmonization (Dobos et al., 2010). Additional drawback of the Hungarian soil maps that soil test methods are not always compatible with standard international methods thus, published procedures are rarely applicable directly e.g. for assessing water or oil retention of soils (Tóth, 2010; Hernádi, 2012; Tóth et al., 2013).

We had the objective to assess a detailed oil retention map for an area at Keszthely from usual soil test results with help of pedotransfer functions developed in earlier studies and in this study.

Materials and Methods

No. 5258/4 (Keszthely) sheet of the oldest soil map (Ébényi, 1942) was selected for our study to assess oil retention. The study area was 266 km^2 large and located at the western tip of Lake Balaton, Hungary. A quarter of the area is covered by forests of the Keszthely-hills where no soil sampling and mapping were done. Legacy soil surveys covered only the agricultural land with a non-uniform spatial distribution therefore only a nearly rectangular area of 175.2 km^2 with high and uniform point density was retained for final interpretation (Figure 1).

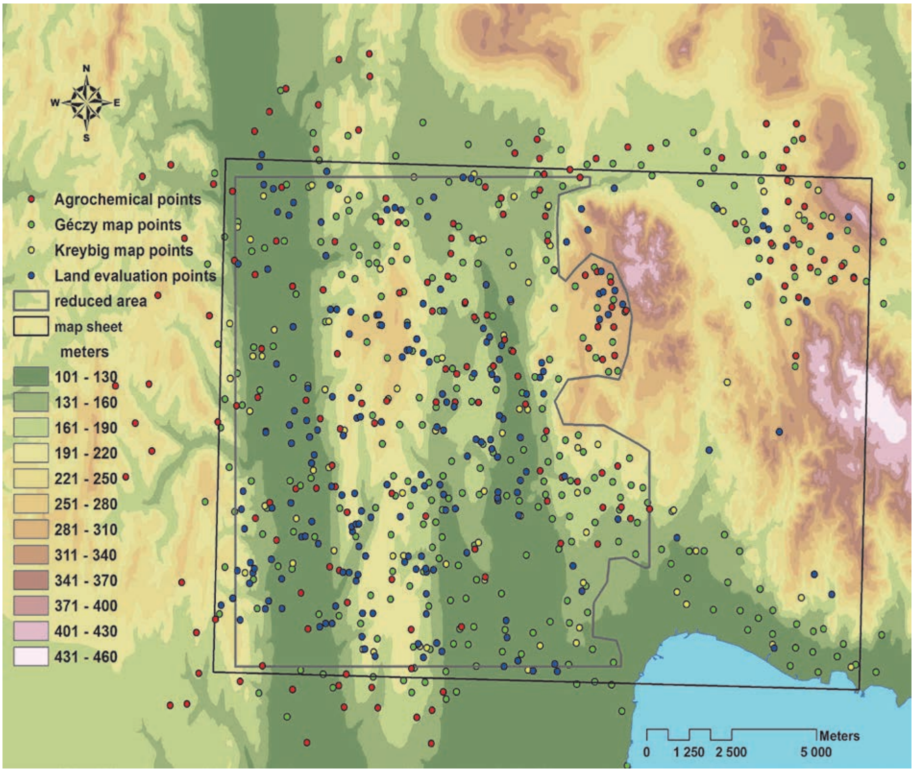

Figure 1. Study area, assessment area, location and source of legacy soil data

In a previous study, we assessed fine scale soil physical properties of the study area (Sisák and Pőcze, 2011). Four legacy data sources were used. 1.) Kreybig soil maps were among the first fine-scale national soil maps in Europe (Kreybig, 1937). The mapping went on between 1932 and 1952. Data on capillary rise of water (mm) for the surface layer were used. 2.) Géczy (1960) published principles of a soil survey. The mapping went on between 1958 and 1961. The purpose of the survey was to improve the data quality of the Kreybig soil maps. Data on field assessments of the texture classes and derived clay content in the surface layer were used. 3.) In the era of the collective agriculture in the 1970's and 1980's, large agricultural companies were obliged to investigate soils regularly for better planning fertilizer use. Data on liquid limit according to Arany was used from this agrochemical soil database. 4.) Research was started in the 1970`s to change the old land evaluation system in Hungary. Soil profile descriptions, laboratory investigation data of the soil samples and high precision coordinates of the reference sites are available. Liquid limit according to Arany for the surface layer was evaluated. We have assessed from these data sources (Sisák and Pőcze, 2011) liquid limit according to Arany for the surface soil of the study area, since this is the usual soil test in Hungary for soil physical properties (Figure 2). The basic method of analysis was main component kriging.

Soil organic matter data were only available for the last two sources (agrochemical and land evaluation database). Kriging was used to interpolate point results for the reduced study area. However, these sources insufficiently covered areas with natural vegetation, thus organic matter for large peat areas was inaccurately estimated. Therefore, we incorporated results from an earlier study (Sisák and Bámer, 2007) to correct recent estimates. The previous study used densely placed sampling points, polygon maps and inverse distance weighted method to assess organic matter in Histosols (Figure 3).

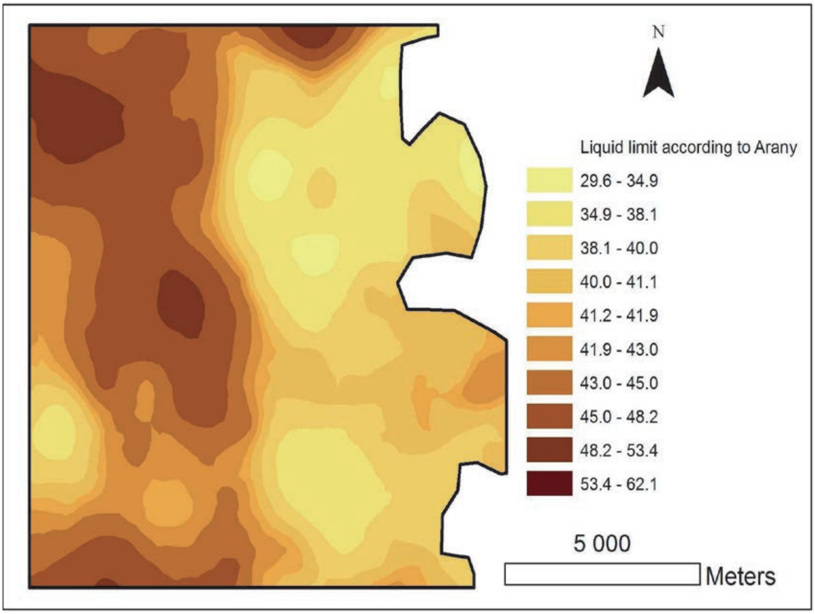

Figure 2. Assessed liquid limit values

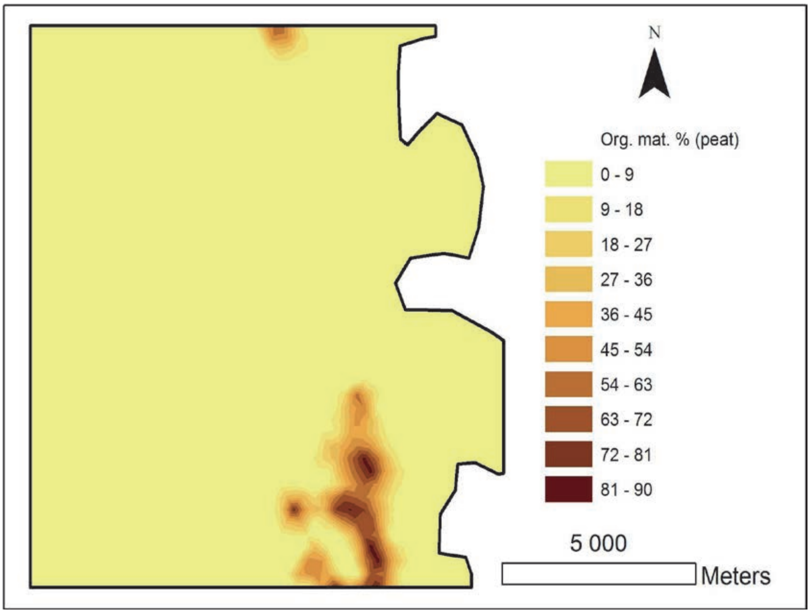

Figure 3. Assessed organic matter content of Histosols

Makó (2002) investigated soil samples from 35 horizons of 12 soil profiles collected in the region to establish relationship between oil retention and other soil properties. Later on he has refined his analysis (Makó, 2005) and calculated the following empirical relationship:

$$\mathbf{OilRet = 26.631 - 0.45*S - 2.231*OM + 4.49*10^{-2}*S*OM + 3.98*10^{-3}*S^2 + 0.208*OM^2}$$

N= 70 R^2= 0.771,

where OilRet: oil retention vol % at one bar pressure; S: % sand content of soil; OM: % organic matter content of soil; N: number of samples; R^2: determination coefficient.

Sand content is not included in the usual soil tests. However, Makó et al., (2010) compiled the MARTHA soil physical database for Hungary which includes usual soil tests (e.g. liquid limit according to Arany and organic matter content) and also particle size distribution data among others. This database allowed us to calculate liquid limit distribution within the texture triangle and also the frequency distribution of data within the texture triangle. Having combined the two distributions, the most probable sand, silt and clay percentages could be determined for each liquid limit categories.

We have converted liquid limit map (Figure 2) to the most probable sand content map and we used sand and organic matter base maps to determine oil retention of the soil surface layer according to the method of Makó (2005).

At the end, we have compared the 50 m by 50 m pixel estimates with the original oil retention data measured by Makó (2002).

We used ArcMap 9.3 for all the spatial analyses.

Results

Liquid limit is generally a function of soil colloid quantity and quality (organic matter, clay minerals, oxides, calcium-carbonate). A modified liquid limit procedure was proposed by Arany (1943) to meet needs for information on soil physical properties. It is a cheap and quick method which became national standard in Hungary in 1978. Its value is equal to the mL of water in 100 g soil when the yarn test is positive (Sisák et al., 2001). It is not surprising that same liquid limit values can be measured on soils with various colloid content. We have determined its distribution within the texture triangle for soils which are similar to the soils in our study area: mostly Luvisols and Cambisols (Figure 4). Extreme sandy and clayey soils can be precisely determined based on the liquid limit according to Arany but one value may represent a wide range of soils with transitional particle size distributions.

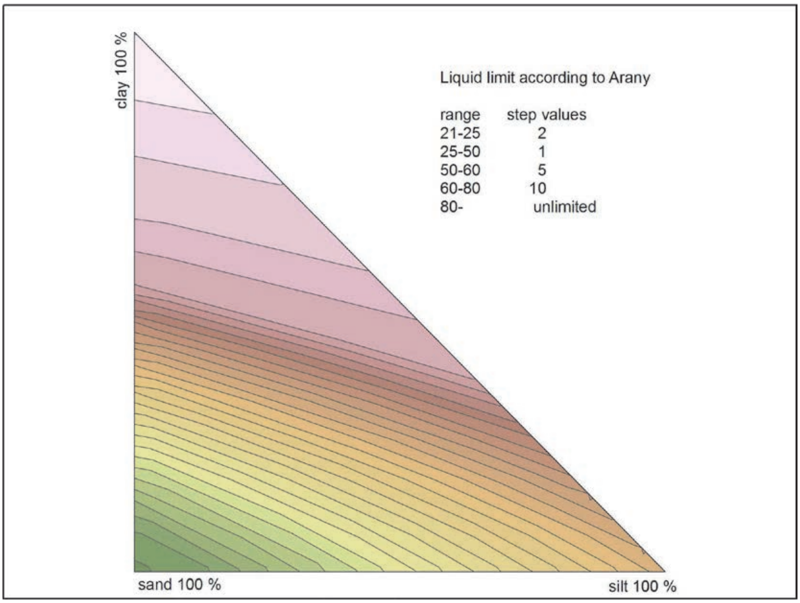

Figure 4. Liquid limit distribution within the texture triangle

However, the probability of the different sand silt and clay fractions are not the same. We have estimated the kernel density function of the data points within the triangle diagram for the same group of soils and we got Figure 5.

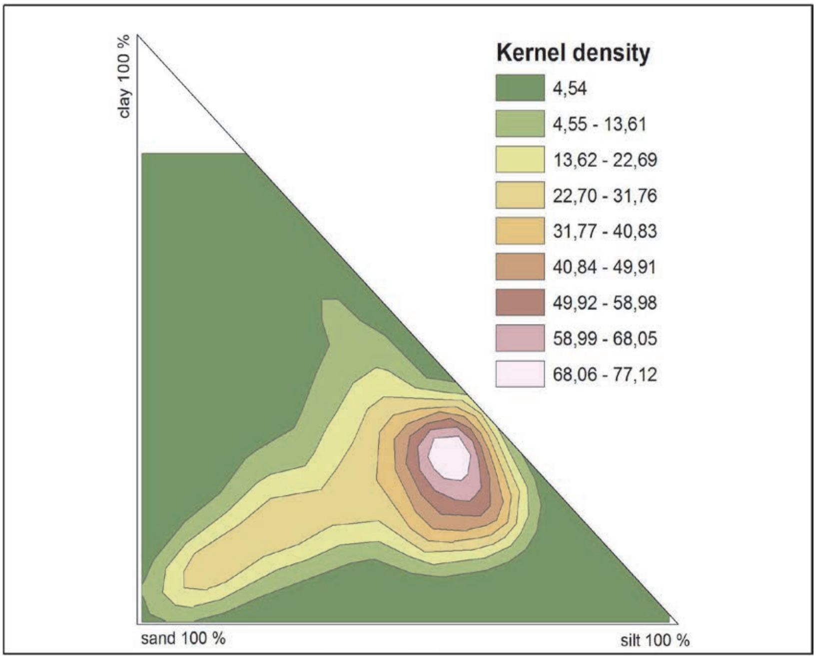

Figure 5. Data density distribution within the texture triangle

By combining the two distributions, we were able to calculate the most probable sand, silt and clay contents for each liquid limit categories (Figure 6.). We used this relationship to assess sand content map for the study area (Figure 7) based on liquid limit map from the earlier study (Figure 2).

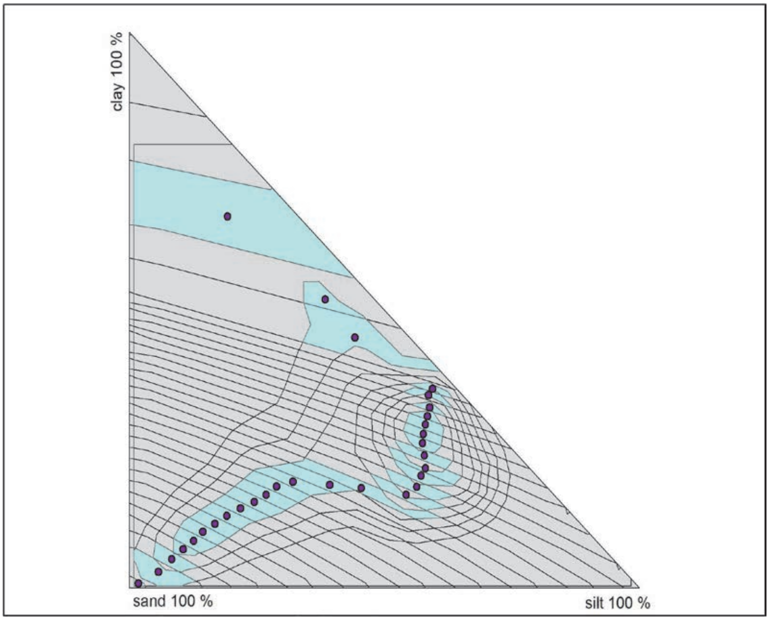

Figure 6. Intersection of liquid limit and data density and the most probable values

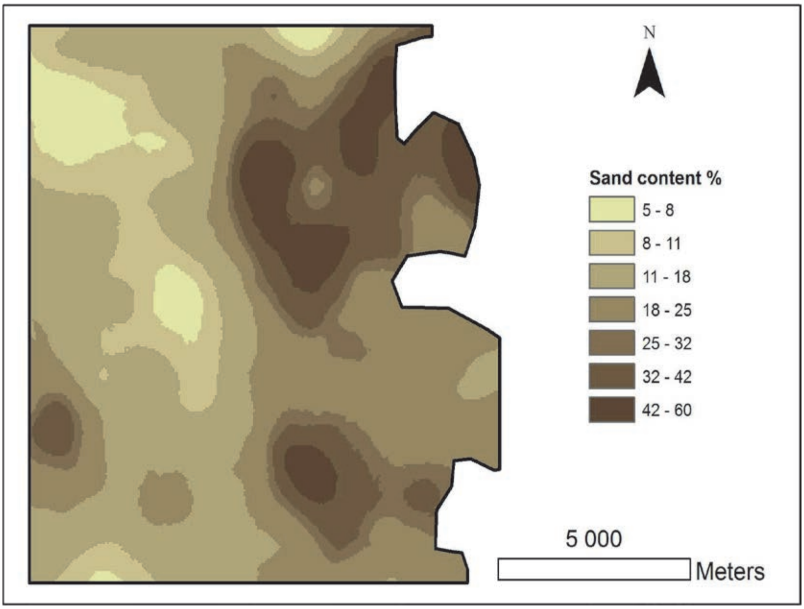

Figure 7. Estimated sand content map

Point data from the agrochemical and land evaluation databases were used to spatially assess organic matter content by kriging. Previous assessment (Figure 3) was superimposed to this map in order to accurately represent Histosols. The resulting map can be seen on Figure 8. The intervals of categories are strongly different in order to accurately depict both mineral and organic soils.

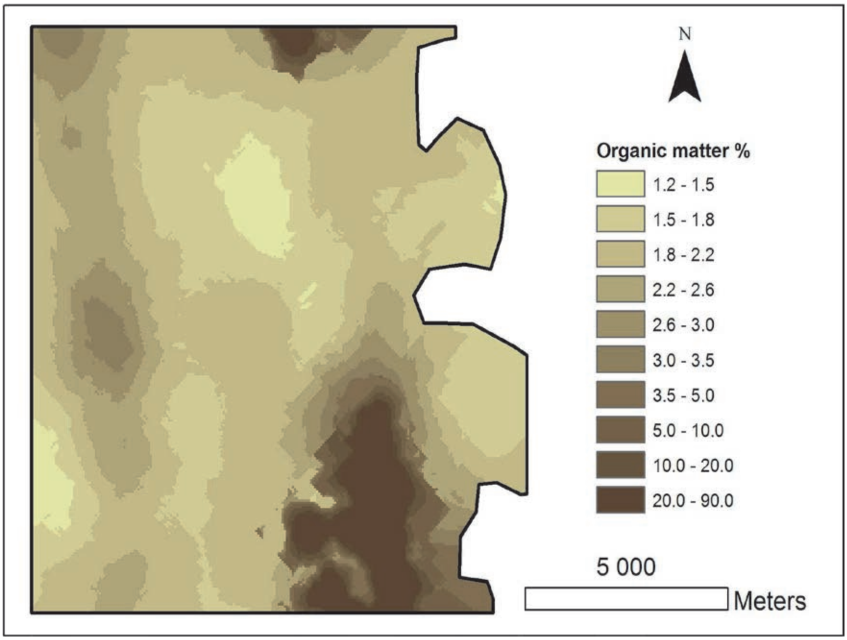

Figure 8. Estimated organic matter map

Organic matter and sand content maps (Figure7 and 8) were used to assess oil retention map for the study area (Figure 9).

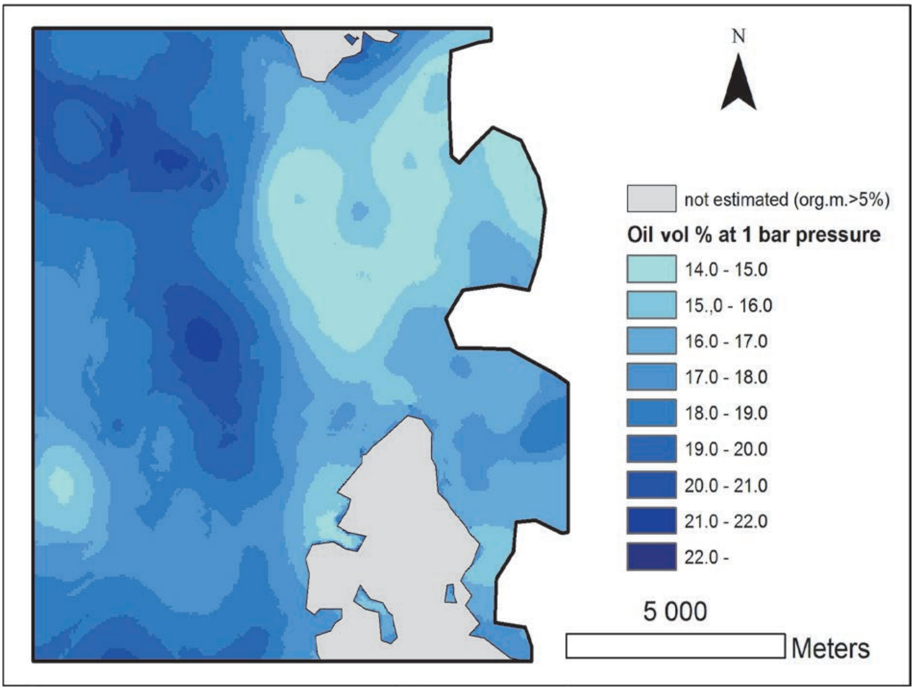

Figure 9. Estimated oil retention map

Discussion

Validity of assessments is always limited by the data which are used to develop relationships and equations. The original data set to derive oil retention equations (Makó, 2002) contained samples with sand content between 5 and 60 percent and with organic matter content between 1 to 5 percent approximately and the measured oil retention varied roughly between 8 and 42 percent. The soils in our study area had a sand content within the same range but organic matter content of Histosols far exceeded 5 % (Figure 7). Therefore, we excluded these areas from estimation (Figure 10). Organic material has high adsorption capacity for non-aqueous liquids and that favour oil retention but the very low bulk density and very high porosity of Histosols pose little barrier for any liquids. After excluding soils with excessive organic matter content, we had approximately the same ranges for the original data set and for our study area regarding sand and organic matter content. But this was not the case for oil retention values (Figure 10).

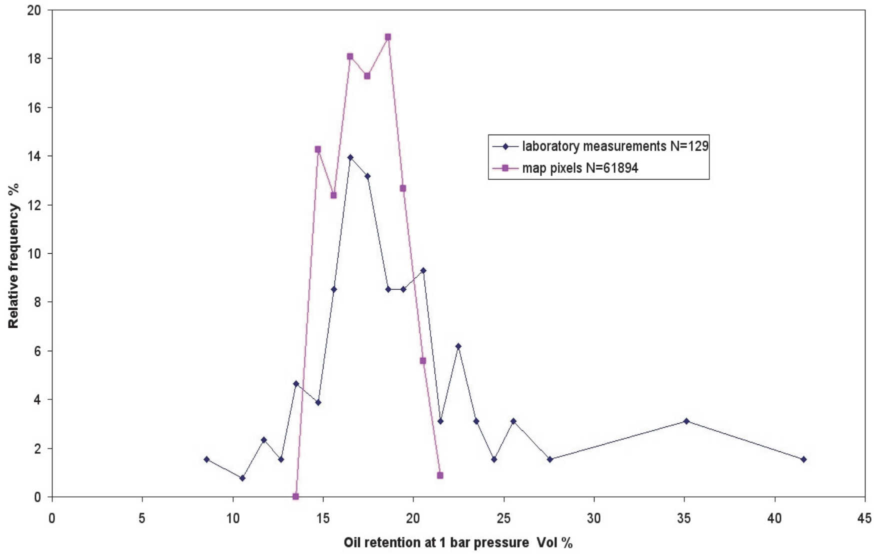

Figure 10. Distribution of original and estimated oil retention data

The average for the samples was 17.3 vol % (standard deviation: 5.5) while for the pixels of the estimated map, it was 19.1 vol % (standard deviation: 1.7). The range of the estimated data was much smaller than that of the original data set in spite of the large number of estimated pixels. The reason can be mainly attributed to the methods of estimation. Both regression analysis in the studies of Makó (2002, 2005) and kriging (Sisák and Pőcze, 2011) are oriented toward central tendency and handle extremities as errors. Recently developed methods which consider real distribution of inputs and produce expected distribution of outputs by Monte-Carlo simulation with subsets of data (such as Bayesian-method) may bring more realistic results in terms of the predicted liquid (oil) retention (Chiu et al., 2012).

Soils usually have three phases (solid, liquid and gaseous) and even dry soils contain bound forms of moisture. Water content of soils strongly influences wetting with non-aqueous phase liquids hence oil retention is reduced by the concurrent water phase (Makó and Hernádi, 2012). The measurements by Makó (2002, 2005) were done with air dry soils therefore, his results represent maximal oil retention and the same is true for our estimated map.

Liquid limit data must not only be influenced by individual colloid materials but by their interactions, too. Even if liquid limit according to Arany has been widely used in Hungary for the last half century this interaction is not well understood or at least not quantified. Further investigations must be done to clarify interactions which should help to build better prediction models to derive rarely measured sand, silt and clay contents of soils.

Generally, real fine scale spatial variability of soil properties including that of particle size distribution and organic matter content is insufficiently known. Digital soil mapping aims at better predict soil properties with help of ancillary variables (McBratney et al., 2003) but fine scale assessments are still far from satisfactory as evidenced by many studies including our own investigation (Sisák and Pőcze, 2011). Better understanding of spatial variability and better models for crucial soil properties are needed.

Acknowledgement

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