Geostatistical analysis of surface soil texture from Zala county in western Hungary

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Abstract Soil texture is one of the most important soil properties governing most of the physical, chemical and hydrological properties of soils. Variability in soil texture may contribute to the variation in nutrient storage and availability, water retention and transport and binding and stability of soil aggregates. It can directly or indirectly influence many other soil functions and soil threats such as soil erosion. Geostatistics has been extensively used for quantifying the spatial pattern of soil properties and Kriging techniques are proving sufficiently robust for estimating values at unsampled locations in most of the cases. In our study, we show the applicability of Ordinary Kriging techniques to characterize the spatial variation of soil texture *i.e.* sand and clay content on the basis of 100 samples collected over a forest mixed agriculture farming area covering about 250sq. km of Zala County in western Hungary. Our study supports the usefulness of geostatistical techniques to analyze the spatial distribution of soil texture content. The results (provided in terms of prediction maps and their associated variance) can be used as a source of information for the development and implementation of any further land management and soil and water conservation plans in the study area.

Keywords Soil texture, Variogram, Ordinary Kriging

INTRODUCTION

Spatial variability is a well known phenomenon of soil systems and this variation in soil has been recognized for many years (Burrough, 1993). The variability in soil properties in any landscape is an inherent natural phenomena conditioned by geological and pedological settings. However, some of this variability may also be induced by tillage and other soil management practices and are in many cases influenced by the factors like soil erosion and deposition. Among the soil properties concerned, soil texture is one of the important soil properties governing most of the physical, chemical and hydrological properties of soils. Variation in soil texture in the field directly contributes to the variation in nutrient storage and availability, water retention, availability and transport hence may influence the yield potential of any site. Warric and Gardner (1983) found a significant impact of this variability on soil performances and therefore the crop yield. Similarly, Tanji (1996) has shown that among the different soil physico-chemical properties measured, variability in soil texture component is a primary soil factor influencing crop yield. Reynolds (1970) and Crave and Gascuel-Odoux (1997) all found that variation in soil moisture content were directly related to the soil textural variability. Soil aggregation as influenced by higher clay content was the most important soil property influencing the soil loss by splash (Luk, 1979). These findings clearly show that soil texture is a property of primary concern. Hence, there is a great need to investigate the spatial variability of this important soil property through more precise quantification techniques to refine and support different agricultural and land use management practices.

Geostatistics (e.g., Goovaerts, 1997; Webster and Oliver, 2001; Nielsen and Wendroth, 2003) has been extensively used for quantifying the spatial pattern of environmental variables. Kriging has been used for many decades as synonym for geostatistical interpolation and has been proved as sufficiently robust for estimating values at unsampled locations based on the sampled data. In recent years soil scientists focused on using geostatistics and different kriging methods to predict soil properties at unsampled locations and to better understand their spatial variability pattern over small to large spatial scale. (Yost *et al*., 1982; Trangmar *et al*., 1987; Miller *et al*., 1988; Voltz and Webster, 1990; Chien *et al*., 1997; Tsegaye and Hill 1998; Lark, 2002).

In this study, we applied Ordinary Kriging (OK) to characterize the spatial variation of soil sand and clay content on the basis of 100 samples collected over a forest mixed agriculture farming area of Zala County in western Hungary. The application of OK in soil studies dates back to 1980's (Burgess and Webster, 1980). During the last two decades it has been widely used in various sub-fields of soil science such as soil reclamation, soil classification and soil pollution studies. Our main objectives are: *i*) to analyze and describe the spatial variable pattern of sand and clay content on the top 30cm of the soil; and, *ii*) to display the variability pattern of these properties through the predicted maps with their associated variances.

MATERIAL AND METHODS

Description of the Study area: The study area is located on the undulating landscape covering about 250 sq. km in the Central-Zala hills in Western-Hungary (Latitude 46°50'0.99"N, Longitude 17°6'14.68"E and mean elevation 113m asl). Climatic conditions can be characterized by an annual mean temperature of 9-10.2^{o}C and with the annual precipitation of 660-800 mm. The geology of the area is characterized by mainly young, tertiary, clayey or sandy sediments (Pannon deposition) and Pleistocene loess. In large areas of the valleys, thick layers of peat can be found on the top of the consolidated earth materials. Main soil types include brown forest soils, texture differentiated meadow and peat bog soils and less developed (or eroded) soils.

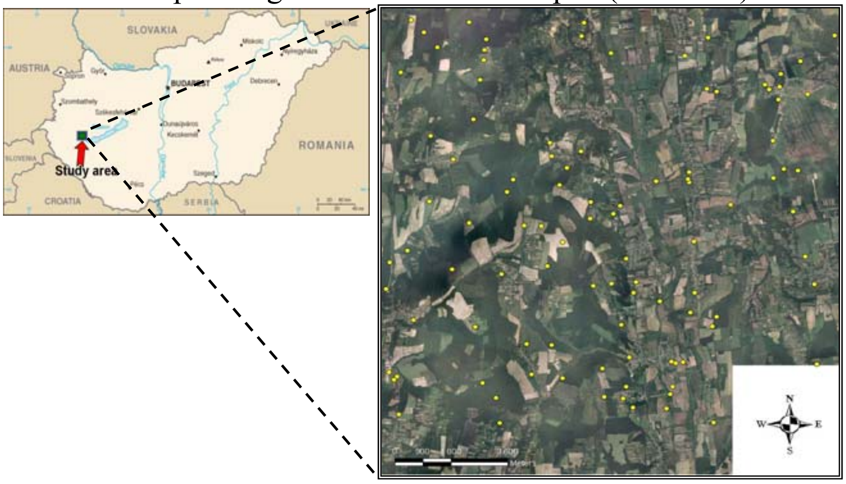

Figure 4. Study area on the map of Hungary showing sampling locations (dots) over the ortho-photo (inset)

Soil data preparation: Here we use information from a data set which has been stored as a Soil Data of the Pilot Area (Zala) in Hungary in the European Soil Data Center (ESDAC) of the Joint Research Center of the European Commission at Ispra in Italy. This data set comprises measured physico-chemical properties of soil including soil texture content coming from each of the identified pedological horizons for 100 sampling locations covering 250 km^2 of the central Zala-hill in western Hungary (1:25,000). The required value of topsoil (0-30 cm) clay and sand content in percentage for each location has been derived as a weighted average of the sand and clay content of the samples coming from soil horizons identified within the first 30 cm of soil.

Data analysis

Statistical analysis

Exploratory analysis includes the computation of frequency histograms and summary statistics of sand and clay content in order to identify the nature and properties of their distribution. The symmetry and peakedness of the data distribution were investigated using coefficient of Skewness (g_1) and Kurtosis (g_2). With null hypothesis (H_0: $g_1 = 0$, and $g_2 = 3$) two student *t*-tests were performed based on these 2 coefficients and the results were compared with the tabulated *t*-values

($t_{0.05,\ 99}$ = 1.985) in order to confirm their normality in the distribution. All statistical analysis was performed with SPSS software.

Geostatistical analysis

To evaluate the spatial structure of the properties, a semivariogram was used which represents the relationship between the lag or any integral multiple of the sampling interval and the semi variance (Goovaertes, 1997). Theoretically, a variogram can be calculated as equation (1):

$$\gamma(h) = \frac{1}{2N(h)} \sum_{\alpha=1}^{N(h)} \{z(x_\alpha + h) - z(x_\alpha)\}^2 \qquad (1)$$

Here, $\gamma(h)$ represents the variogram for a distance (lag) h between observations $z(x_\alpha)$ and $z(x_\alpha + h)$ with $N(h)$ the number of pairs separated by h.

A preliminary variogram surface analysis was performed to check whether there existed any zonal affect or trend in either direction. The omnidirectional experimental variograms for each property were then constructed. Theoretical models were fitted to these. The best fit (in a mean square sense) model for both analyzed properties was a spherical model (equation 2).

$$\begin{aligned} \gamma(h) &= C_0 + C_1\{1.5(h/a) - 0.5(h/a)^3\} \quad & h \le a \\ \gamma(h) &= C_0 + C_1 \quad & h \le a \end{aligned} \qquad (2)$$

Here, a is the range, C_0 the nugget semivariance, and C_0+C_1 the sill or the total semivariance.

In order to see the relative contribution of nugget to the total variance, we calculated the relative nugget effect (*RNE*) according to:

$$RNE = \left[\frac{C_0}{C_0 + C_1}\right] \times 100 \qquad (3)$$

The variogram parameters extracted for each fitted model were used to interpolate the value at unsampled location by means of Ordinary Kriging. The ordinary kriging is an exact interpolation technique which assumes the local stationary of the mean. *OK* uses a linear combination of observations within a predefined neighborhood around x_0 (Goovaerts, 1997). The *OK* estimator $Z^*(x_0)$ with the associated variance $\sigma^2{}_{OK}(x_0)$ can be represented as in equations (4) and (5) respectively.

$$Z^*{}_{OK}(x_0) = \sum_{\alpha=1}^{n(x_0)} \lambda_\alpha z(x_\alpha) \qquad (4)$$

$$\sigma^2{}_{OK}(x_0) = \sum_{\alpha=1}^{n(x_0)} \{\lambda_\alpha \gamma(x_\alpha - x_0)\} + \psi \qquad (5)$$

Here, λ_α is the weight assigned to the n observations, $z(x_0)$, and ψ is the Lagrange multiplier.

RESULTS AND DISCUSSION

Descriptive statistics of the texture data: Table 1 displays the results of the main statistical descriptors of the data sets analyzed. Figure 2 reports the corresponding frequency histograms. On these bases, two outliers are identified, *i.e.*, 79.87 % and 60.54 %, respectively for sand and clay content.

All further statistical and geostatistical analysis were performed with the data after removing the outliers. The average sand content of the study area is 55% and is associated with a coefficient of variation (CV) of 0.26 whereas the average clay content is found to be 21%. The variability of clay is larger than that of sand content, as they are characterized by CV = 0.41 and 0.26 respectively. Skewness coefficients demonstrate that both clay and sand are asymmetrically distributed showing positive skewness for clay (*i.e.*, 1.2) and negative skewness for sand (*i.e.*, -

1.01). Meanwhile, kurtosis coefficients for clay (*i.e.*, 2.09) and sand (*i.e.*, 0.877) indicate a platykrutic behavior in their distribution. For a symmetrical and a normal distribution, these coefficients should be equal to 0 and 3 respectively. With calculated Student-*t* values based on skewness and kurtosis coefficients, (for sand $t_{cal,}$ $g_1 = -4.12$ and $t_{cal,}$ $g_2 = -4.31$; for clay $t_{cal,}$ $g_2 = -1.83$), we confirmed that both distributions are normal although the distribution of clay is not symmetrical ($t_{cal,}$ $g_1 = 4.86$).

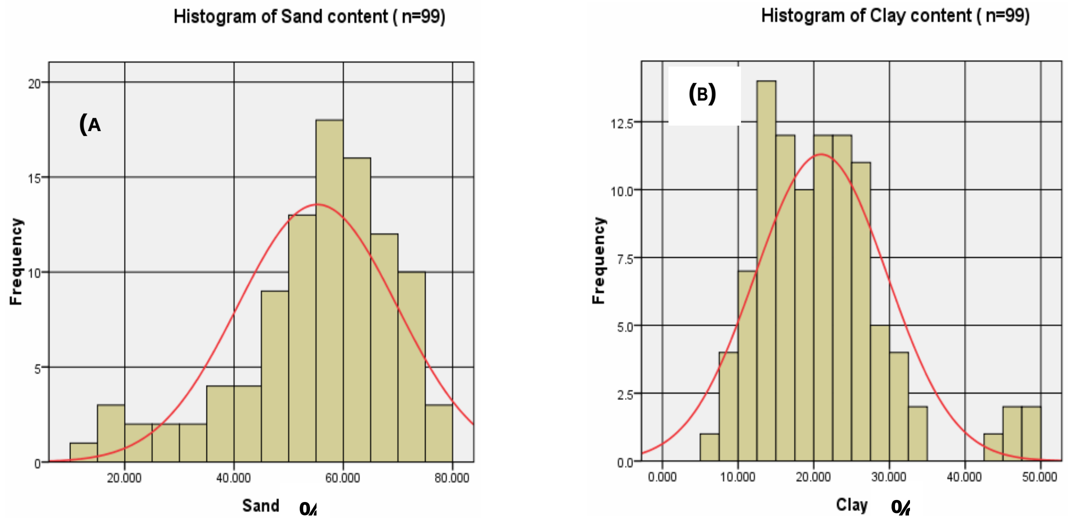

Figure 5. Histogram of (a) sand and (b) clay content and the fitted Normal distributions are indicated as continuous lines

Table 1. Descriptive statistics of sand and clay content with (1) & without (2) outliers

S. No.	Property	Number	Minimum	Maximum	Mean	Std. dev.	CV	Skewness	Kurtosis
1	Sand	100	12.28	79.87	55.48	14.70	0.265	-0.996	0.846
1	Clay	100	5.24	60.54	21.36	9.55	0.447	1.514	3.410
2	**Sand**	**99**	**12.28**	**75.03**	**55.24**	**14.56**	**0.263**	**-1.014**	**0.877**
2	**Clay**	**99**	**5.24**	**49.47**	**20.97**	**8.73**	**0.41**	**1.198**	**2.095**

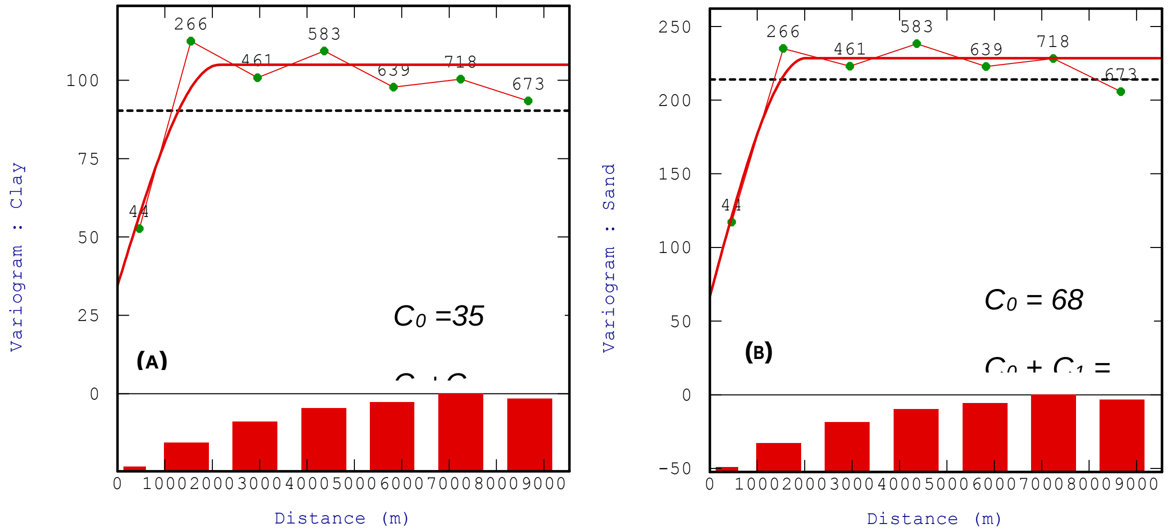

Figure 6. Experimental variograms (dots) and fitted spherical models (continuous curves) for (a) clay and (b) sand content with corresponding variogram parameters. Dotted line is the experimental variance associated with the data.

Variogram construction and analysis: Figure 3 depicts the experimental variograms of sand and clay content, together with the fitted spherical models.

Both sand and clay content displayed a well-defined spatial structure with their characteristics sill and range. As indicated by Frogbrook *et al.* (2002) such variograms suggest that the properties vary in a patchy way resulting in areas with small values and other areas with larger ones. The range of spatial correlation of the variogram provides the average extent of these patches.

The higher range of spatial correlation is associated with clay content reaching >2 km whereas sand shows a bit lower range of 1.9 km. Although both properties show a relatively higher nugget variance, the distribution of sand with *RNE* value 29.82 % seemed to be less influenced by the nugget compared to that of clay which comprises the corresponding *RNE* of 33.65 %.

Mapping soil properties: Ordinary Kriging is employed to estimate the values of sand and clay content at unsampled locations. The continuous maps with their associated uncertaintities for each property over the study area have been displayed in Figure 4.

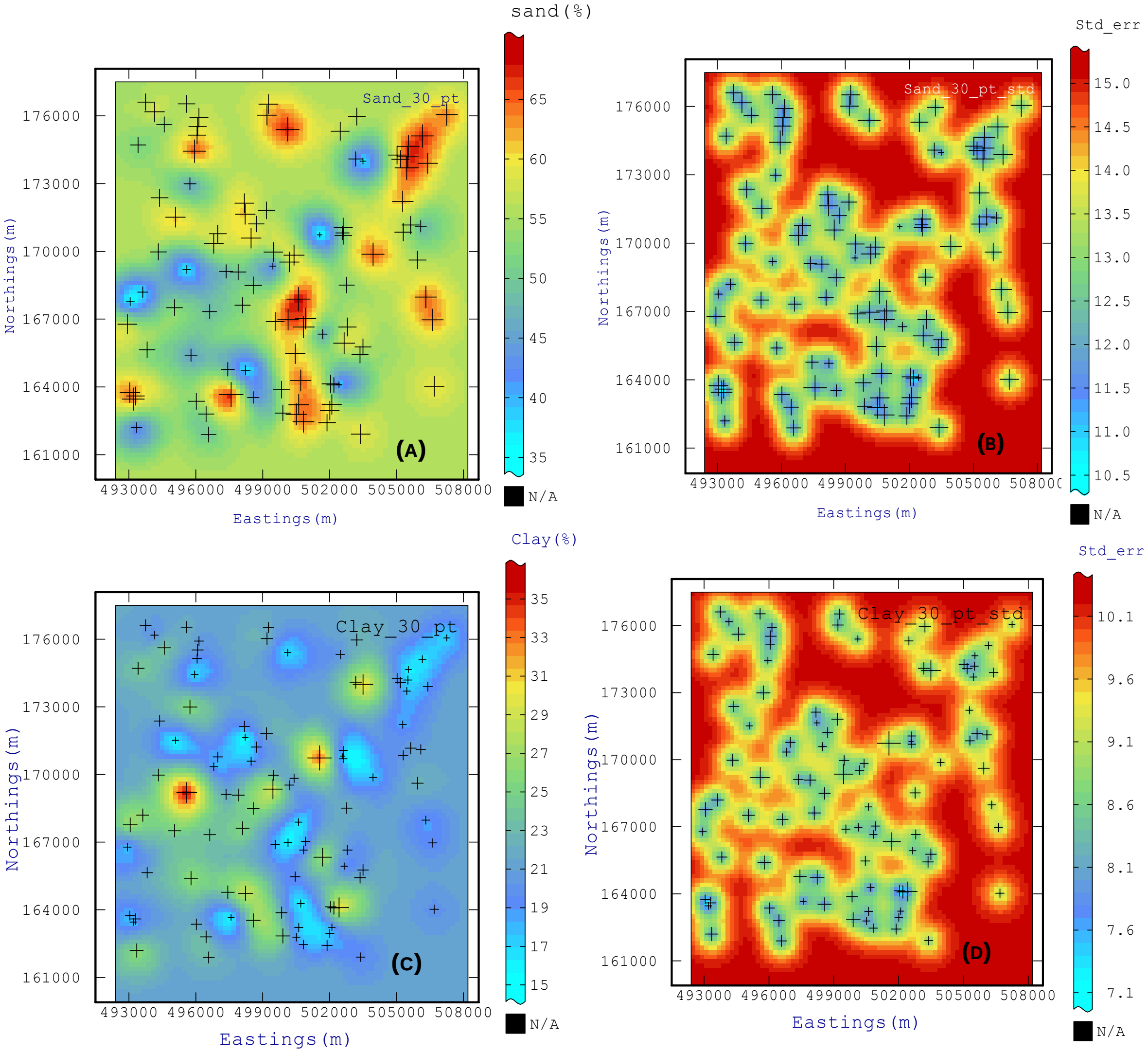

Figure 7 Predicted maps and associated variance; sand (a and b) and clay (c and d) and the "+" sign indicates the measurement points; bigger the size higher the value observed.

Figures 4(**a**) and (**c**) suggest that the entire study area is characterized by a moderate to high level of sand content with only few small areas which are rich in clay. Although the spatial variability of sand and clay content appears in more patchy way as also suggested by the natural behavior of our best fitted model, the distribution of higher sand content areas seems to be more towards the northern west and most of the eastern part of the study area whereas very few clay rich patches appears around the central-west. Moreover, clay is also found to be well distributed through out the area but is always with its relatively lower contents. The areas with higher sand are always associated with the lower clay contents.

Clay and sand content are found to be highly correlated (with a negative correlation coefficient, r = -88 %). We assume that the areas associated with the lower clay contents might be due to the effect of soil erosion or leaching (which removed the easily detachable soil clay leaving behind the course grains on the surface).

The uncertainty maps [Figures 4(**b**) and (**d**)] depict the standard errors related with the mapping.

CONCLUSIONS

The results of our study shows an application of Geostatistics (specifically Ordinary Kriging) to study and analyze the spatial behavior of soil texture contents. The predicted maps thus obtained could be helpful to the farmers and soil management experts to design land management and soil and water conservation plans taking into account the spatial heterogeneity of soil texture. The results of an investigation of this type will be of great interest to environmental scientists, water resources planners, climatologists, decision makers, and resources managers. As the properties analyzed display a significant correlation, mapping of either variable could be improved by using co-kriging techniques. Moreover, in line with these out comes we suggest for further analysis by using other data layers like topographical parameters, land use, parent material, soil erosion and any other information which might influence the spatial distribution of soil texture in the central Zala-hill of western Hungary.

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