# Compilation of a 3D soil physical database for the unsaturated zone

Zsófia Bakacsi, **László Pásztor** and József Szabó

Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, Hungary, Email pasztor@rissac.hu

## Abstract

The most commonly used basis for the estimation of soil hydraulic parameters is the particle-size distribution (PSD) data or class pedotransfers. In this paper we outline an attempt for compilation of an integrated and harmonized stratified soil physical database for a model area, using different origin data sources. Due to their appropriate spatial and thematic resolution and data processing status, the Digital Kreybig Soil Information System (DKSIS) and Hungarian Agrogeological Database were chosen as pedological and agrogeological data sources of the database, which were able to describe the soil physical properties in the unsaturated zone. The resulted database characterizes the distinguished soil and sediment layers –have at least 10 cm thickness- for a 690 km$^2$ model area, describing their thickness and texture classes to the depth of the permanent groundwater level, in every single square kilometer cell of the model area. The compiled database is indispensable in coupled (deterministic - stochastic) model simulation based analysis of regional water management problems like drought, flood and inland inundation.

## Key Words

Spatial soil information system, stratified soil physical data, unsaturated zone, data harmonization.

## Introduction

Describing the water movement in the unsaturated zone, numerous soil hydraulic data as input parameters are required concerning the water retention curve and the hydraulic conductivity function as the main hydraulic properties. Because of the direct measurement of the hydraulic parameters is difficult and time-consuming, the estimation of them can be an alternative. The most commonly used basis of the estimation is the particle-size distribution (PSD) data or class pedotransfers (e.g. Rajkai *et. al* 1996; Tietje and Hennings 1996; Hwang and Powers 2003). Based on the Unsaturated Soil Hydraulic Database of Hungary (HUNSODA) Nemes (2002) defined the main hydraulic parameters for each texture class both in the FAO and USDA classification system.

The aim of our work was to compile the first version of a stratified soil physical database, describing the soil physical properties and stratification of the formations to the depth of the permanent groundwater level. Usually, the strength of a pedological dataset is the detailed description of the surface and subsurface horizons of the soil; however the depth of the soil profiles is limited and does not explore the whole unsaturated zone. Close to the surface an agrogeological dataset is less sensitive for the fine stratification than the pedological one, but the depth of the boreholes is used to be enough for the description of the whole unsaturated zone.

Since the existing pedo- and agrogeological databases are not able to serve separately the 3D model requirements, their integration was necessary. Using different origin data sources for harmonized database construction is common, especially in those cases when the accessible individual datasets cannot fulfill the requirements, e.g. in a transboundary soil database (Dobos *et al.* 2008). Large amount of soil information in different spatial and thematic resolution is available in Hungary, in different data processing status. The existing Hungarian Soil Monitoring network points (1200 sites) have had detailed profile description and measured particle size distribution data since 1992, but its spatial resolution is not adequate in the target area. For less than half of the territory of Hungary 1:10, 000 scale soil maps and site descriptions would be available, but the described areas are fragmented and just at the beginning of GIS processing.

## Materials and Methods

### *Processing of pedological data*

The Digital Kreybig Soil Information System (DKSIS) compiled in the Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, based on the first national soil mapping program (1933-44, and after war, till 1951) in Hungary. The survey sheets are 1:25,000 scale mounted topographic maps (area about: 25 000 ha), which indicate field observations and contain the original location of the reference sites (Pásztor *et al.* 2010). Even though some of the laboratory methods have been changed, the field, -and laboratory data of the Kreybig archive represent valuable information on soil physical/chemical properties (e.g. texture, pH-value, exchangeable acidity, carbonate- and salt content) and can take into account as „baseline values" comparing with the present-day condition (e.g. acidification, salinization). Lack of measured PSD data, the field estimation of the textural classes, air dry soil moisture content and the so-called "capillary rise of water" defined the texture classes (Kreybig 1937). In the latter method, a 100 cm high (20-25 mm caliber), open-end glass-cylinder was filled up with ground soil sample and stand in water. The capillary rise is recorded in consecutive 5 h, 10 h, 20 h and 100 h intervals. In Kreybig-survey time the "capillary method" has been widely used and accepted, but because of its debated reproducibility, has become unaccepted. The so-called "air dry soil moisture content" in the explanatory booklets, practically means hygroscopic moisture content (hygroscopicity, *hy*), mainly according to Kuron (Mados 1938). The capillary rise and especially the *hy* values could be take into consideration in fine texture class definition (Filep and Ferencz 1999), but regarding the Kreybig database, the verification reliability of legacy data relation to the texture classes was not proved to our satisfaction.

From the 1940s till nowadays, the so-called plasticity index according to Arany ($K_A$) has been an accepted "low-cost" method for texture class definition (Ballenegger 1962) in the Hungarian practice. Determination of $K_A$ in laboratory is similar to the saturation percentage (SP %), but requires another consistency status and its values are approx. 10 percent lower than the SP values (Búzás 1993). At the time of Kreybig survey the laboratory routine had not extended for the $K_A$ determination, but in 2009 a unique explanatory booklet from 1944 with measured KA data was emerged (num. 5264/3 from Alpár region). The legacy $K_A$ values could serve as a link between Kreybig laboratory data and the applied texture class definition in the practice today. The relation of $K_A$ values and the applied texture classes with hygroscopicity and capillary rise values are shown in Table 1.

**Table 1. Hungarian conventional texture classes for practical purposes, their relation to hygroscopicity, 5 hours capillary rise values and plasticity index according to Arany (based on Ballenegger 1962; Stefanovits *et al.* 1999).**

| texture classes | hy (%) | capillary (mm) | KA |
|---|---|---|---|
| coarse sand | < 0,5 | - | < 25 |
| sand | 0,5-1,0 | > 300 | 25-30 |
| sandy loam | 1,0-2,0 | 250-300 | 31-37 |
| loam | 2,0-3,5 | 150-250 | 38-42 |
| clayey loam | 3,5-5,0 | 75-150 | 43-50 |
| clay | 5,0-6,0 | 40-75 | 51-60 |
| heavy clay | > 6,0 | < 40 | 61-80 |

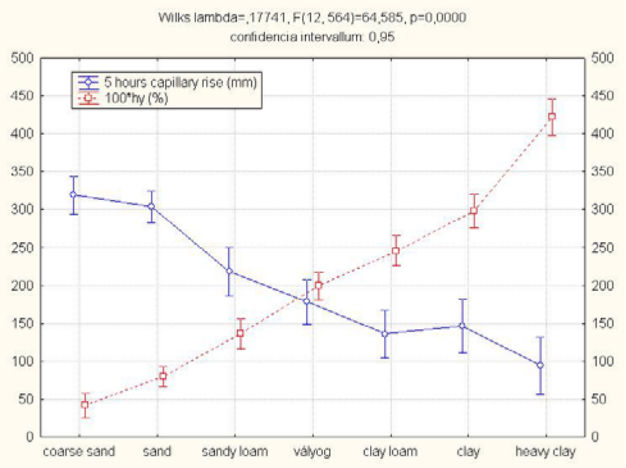

**Figure 1. 5 hour capillary water rise (mm) and hygroscopicity values (multiplied by 100) according to the Hungarian conventional texture classes as categorical factor, based on 290 data origin from the Alpár (num. 5264/3) map sheet.**

At the 5264/3 sheet, for 290 samples the measured capillary water uptake and hygroscopicity has good empirical relation with the textural classes of the sample according to their plasticity index. In each texture class the standard deviations of capillary rise values are higher than the hygroscopicity ones. The capillary rise seems to be less reliable at the clay-heavy clay classes, but we should take into consideration the weakness of the plasticity index (Ballenegger 1962) in this measuring range (Figure 1).
The 690 $km^2$ large Szentes model area is situated on the southeastern part of the Great Hungarian Plain, developed on alluvial sediments of Tisza River and tributaries. In the DKSIS 649 soil mapping units cover the model area, 582 of them are agricultural land and 67 of them with other land use (forest, settlement, waterlogged area). 484 sites of soil profiles as point features were joined to the polygons, using "one representative point to one polygon" method, and characteristically each profile has two or three horizons (with approx. 1200 samples). There was not soil description for the non-agricultural lands; these polygons

were affiliated to their largest neighbor.

During the data processing the inconsistent field vs. capillary or *hy* data pairs was excluded. Sand, sandy loam, loam, clay loam and clay classes were defined according to the Hungarian practice.

*Processing of agrogeological data*

The agrogeological dataset belongs to the Hungarian Geological Institute and derives from 10 m depth boreholes drilled in the period of 1964-1985. In the model area the exposed 152 boreholes are along an equidistant grid, drilled 3.5 km from each other. According to the agrogeological method all the different geological formations were sampled, at least in each 1.0 m. Based on the description and particle size distribution data, 110 similarly stratified patches were delineated on 1:100 000 scaled maps. 134 boreholes (with approx. 2000 samples) have complete stratification description and PSD analysis. The geological practice for describing the sediments differs from the pedological nomenclature; therefore we turned back to the detailed PSD data and re-defined their particle-size classes according to the USDA triangle (Soil Survey Staff 1975). The used particle-size intervals in the Hungarian geological practice slightly differ from the pedological requirements. They measure the clay fraction (< 0.002 mm), but define the silt/sand size limit at 0.06 mm, while it is 0.05 mm in the pedological practice. Numerous interpolation methods are used for estimation of missing particle-size classes (e.g. Buchan 1989; Rousseva 1997; Nemes *et al.* 1999). In our "first approximation" considering the silt/sand limitation differences (0.06 mm in place of 0.05 mm) loglinear interpolation method was used. Significant gravel-sediments (over 2 mm grain size) were not exposed in the unsaturated zone, so it was not necessary to re-calculate the grain size distribution only for the earth fraction before arranging data in textural triangle. We defined texture classes based on the clay-silt-sand triangle, and divided the agrogeological samples into 12 classes according to the USDA classification. Most of the samples were fine-grained silt sediments.

## Results

Both in the DKSIS and agrogeological maps, the spatial extension of the polygons varied, in the large patches numerous islands-like polygons can be found with the same attributes. The place of the profiles and boreholes as point features was joined to the polygons, using "one to one" method, and after spatial joining, the polygons got "deepness", as third dimension from the attribute table of the point data (Figure 2). For the calculation of the km*km grid content, the vector maps was converted into raster format. The structured (depth and texture) data follow each other not equidistantly; the resulted data layers preserve the stratification characteristic of the profiles and boreholes.

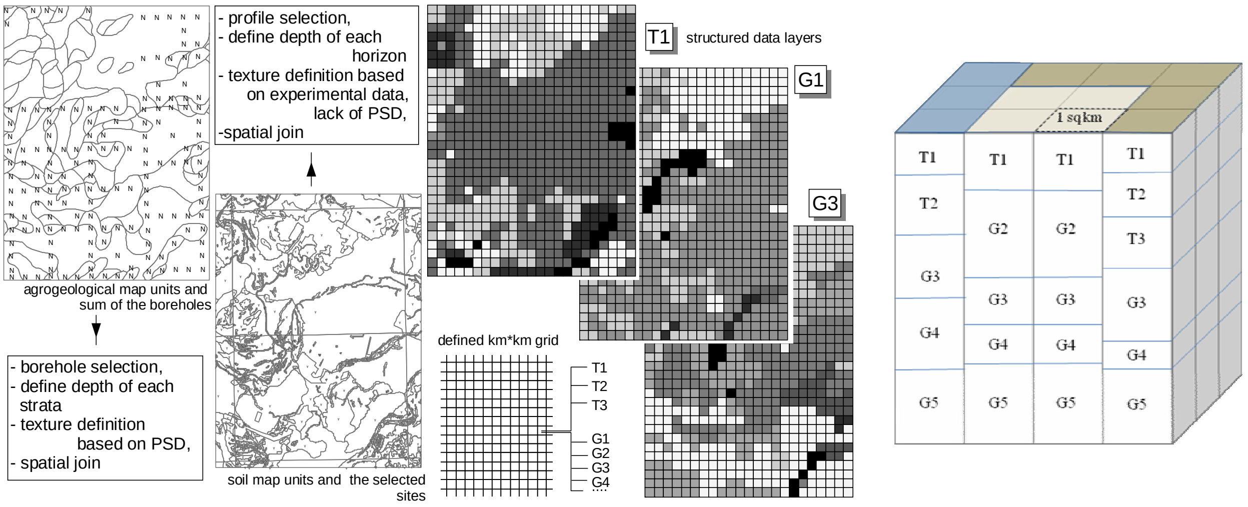

**Figure 1. Summarizing the main stages of database compilation. The colored grids illustrate the spatial distribution of the different textures in the selected layers (left), and a conceptional cube (right) to demonstrate the spatial structure and resulted stratification of the database down to the fifth agrogeological depth interval.**

Because of the same texture name according to the Hungarian "practical" nomenclature and the USDA triangle does not cover necessarily the same hydrological character, for further studies and hydrological characterization the database reserve the origin of the layers and the data from the DKSIS were coded as "T", the others, noted their agrogeological origin, as "G". The repetitions were excluded regarding the same depth interval originating from the DKSIS and agrogeological data and the layers with less than 10 cm thickness, too. Describing the structural diversity of the pilot area, 9 kinds of layer-combinations fitted to requirements T1T2T3G3G4 (184 case num.); T1G2G3G4G5 (170); T1T2T3G2G3 (137); T1T2G2G3G4 (137); T1T2G3G4G5 (44); T1T2G2G3G5 (7); T1T2T3G4G5 (6); T1T2T3G3G5 (4); T1T2G4G5G5 (1).

## Conclusion

The compiled stratified soil physical database for the unsaturated zone can be the base of soil hydraulic parameter estimation, which can serve as input data for soil hydrological modeling. The database structure reflects both the fine stratification of the soil layers near to the surface, and the sedimentation of the parent material and deeper structures, frequently down to 10 m. Its adaptation and spatial extension for larger area makes possible the more realistic description of vadose zone, accommodating to the hydraulic model requirements, solving regional water management problems.

## Acknowledgements

The present work was partly founded by the WateRisk Project (TECH_08-A4/2-2008-0169) and the Hungarian National Research Foundation (OTKA, Grant No. NK73183). The authors are grateful to the staff of RISSAC GIS Lab: Judit Matus, Zita Krammer, Annamária Laborczi and Szilvia Vass-Meyndt.

## References

Ballenegger R (1962) Talaj- és tápanyagvizsgálati módszerek (in Hungarian). Mezőgazdasági Kiadó, Budapest

Buchan GD (1989) Applicability of the simple lognormal model to particle-size distribution in soils. *Soil Science* **147,** 155-161.

Búzás I (1993) Talaj- és agrokémiai vizsgálati módszerkönyv 1 (in Hungarian). INDA 4231 Kiadó, Budapest.

Dobos E, Bialkó T, Michéli E (2008) Határon átnyúló talajtani adatbázisok készítése digitalis talajtérképezési eszközök segítségével (in Hungarian). *Talajvédelem* special issue, 577-584.

Filep Gy, Ferencz G (1999) Javaslat a magyarországi talajok szemcseösszetétel szerinti osztályozásának pontosítására (in Hungarian). *Agrokémia és Talajtan* **48,** 305-320.

Hwang SI, Powers SE (2003) Using Particle-Size Distribution Models to Estimate Soil Hydraulic Properties. *Soil Sci. Soc. Am. J.* **67,** 1103-1112.

Jamagne M, King D, Le Bas C, Daroussin J, Burill A, Vossen P (1994) Creation and use of a European Soil Geographic Database. In ‘15th International Congress of Soil Science, Transactions, Commission V, Symposia’, Acapulco, Mexico, Vol. 6a, pp. 728-742.

Kreybig L (1937) The survey, analytical and mapping method of the Hungarian Royal Institute of Geology (in Hungarian and German). M. Kir. Földtani Intézet Évkönyve, 31, 147–244.

Mados L (1938) A higroszkópos nedvesség, mint a talaj kötöttségi állapotának jellemzője (in Hungarian). Mezőgazdasági Kutatások, XI. évf. Budapest, pp. 217-229.

Nemes A, Wösten JHM, Lilly A, Oude Voshaar JH (1999) Evaluation of different procedures to interpolate particle-size distributions to achieve compatibility within soil databases. *Geoderma* **90,** 187-202.

Nemes A (2002) Unsaturated Soil Hydraulic Database of Hungary: HUNSODA. *Agrokémia és Talajtan* **51,** 17-26.

Pásztor L, Szabó J, Bakacsi Zs (2010) Digital processing and upgrading of legacy data collected during the 1:25 000 scale Kreybig soil survey. *Acta Geodaetica et Geophysica Hungarica* **45**, 127-136.

Rajkai K, Kabos S, van Genuchten MTh, Jansson P (1996) Estimation of water-retention characteristics from the bulk density and particle-size distribution of Swedish soils. *Soil Science* **161,** 832-845.

Rousseva SS (1997) Data transformations between soil texture schemes. *European Journal of Soil Science* **48,** 142-147.

Soil Survey Staff (1975) Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA/SCS Agricultural Handbook No. 436, U.S. Government Printing Office, Washington, D.C., USA.

van Genuchten MTh (1980) A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.* **44,** 892-898.