Elaboration, verification, upgrading and refinement of a large-scale, national, spatial soil information system

László Pásztor, József Szabó
PhD-Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences, GIS Lab, Budapest, Hungary
pasztor@rissac.hu

SUMMARY

Digital reambulation and GIS adaptation of the soil information originating from the 1:25,000 scale practical soil mapping of Hungary is a challenging task. Compilation of Kreybig Digital Soil Information System (KDSIS) involves both its integration within appropriate spatial data infrastructure and updating with efficient field correlation, which make an inherent refinement and upgrading of the system possible. First attempts for the field-based updating of KDSIS were done using field GIS technology. Elaboration of a detailed, complex national spatial soil information system, processes of desktop and field reambulation are presented in this paper.

KEYWORDS: *spatial soil information system, reambulation, field GIS*

INTRODUCTION

Soil surveys, soil maps, spatial soil information systems, soil geographic databases, spatial soil inference systems are all designed for fulfilling the requirements and demands of society, which increased dramatically in the last decades according to Mermut & Eswaran (2000). Soil information is used for land evaluation, farm and management recommendations, prediction of potentials, limitations, problems, management needs, degradation processes etc. and is applied by land users, planners, policy makers, legislative officiers, engineers, scientists. Recent soil related databases are integral part of rural land management planning (Thwaites 1999), agro-environmental programs, environmental modelling (Hubrechts et al. 1998) as well as land resource assessment (FAO, 1976) and risk evaluation (Lim and Engel, 2003). Burrough (2004), Lagacherie & McBratney (2004) and Rossiter (2004) summarized most recently the state of the art of digital soil databases.

Traditional soil survey is time consuming and expensive, new conventional surveys in the near future are very unlike in the great majority of the world (Nachtergale & van Ranst 2002). According to Zhu et al (2001) with even a hardly affordable rate of soil survey updating a century cycle would be necessary to accomplish the full update of US soil survey. Also due to high cost of soil sampling, methods exploiting existing information are becoming increasingly important. However due to certain discrepancies between the information provided by former surveys and that of required recently, there is a strong pressure on soil science to develop shortcut solutions to fill these gaps. Digital soil mapping, application of auxiliary spatial databases of certain predictive environmental covariables affordable at significant lower costs (McKenzie & Gallant 2005), introduction and calibration of pedotransfer functions (Hubrechts et al. 1998) can facilitate the elaboration of reliable and multi-purpose (possibly multi-scale) spatial soil information systems (SSISs). These tools should however integrate traditional pedological knowledge (Walter et al. 2005) and cannot work without data, which is primarily collected in the field (Webster 1997).

According to position paper of Rossiter (2004) existing SSISs concerns mainly regional or national scale (corresponding cartographic scale less than 1:200,000; spatial resolution greater than 400 m or 16 ha in territorial units). This is not surprising since even survey data is scarcely available in larger scale. On the other hand even if more detailed traditional soil information was available, first initiatives on compiling a complete (e.g. national) SSIS relied on existing generally small scale (frequently generalized) soil maps and data.

Nevertheless more detailed SSISs are strongly expected by numerous potential users. The next step would be the so-called D3 level featured by a scale of 1:200,000 up to 1:20,000 (with a nominal spatial resolution of 40-400 m or 0.16-16 ha in territorial units) (Lagacherie & McBratney, 2004). Even the highly developped countries are not always able to fulfill the expectations of the worldwide developping spatial data infrastructure (SDI) from soil information point of view, either because the existing soil databases are not exhaustive or precise enough. However European Soil Protection Strategy (CEC 2002) requires adequate spatial information on soils, which should be organised according to, INSPIRE principles (CEC 2004) as it was discussed in details by Dusart (2004).

A great amount of soil information is available in Hungary due to agrogeological surveys conducted in the past 150 years. The collected data are available in different scales: national, regional, micro-regional, farm and field level and generally they are related to maps (Várallyay, 2002). However, similarly to the great majority of the world, large scale, comprehensive new surveys cannot be expected in the near future. In the 1990s a great deal, dominantly the small-scale of these soil related data were converted into digital format and organized into SSISs (AgroTopo: Várallyay and Molnár, 1989; HunSOTER: Várallyay et al., 1994; MERA: Pásztor et al., 1998; SOVEUR: Várallyay et al., 2000). Recently the more challenging large-scale systems are coming to the front (Pásztor et al, 2002b; Szabó, 2002). As primary importance the GIS adaptation and digital reambulation of the results of the practical 1:25,000 scale soil-mapping programme hallmarked by Kreybig is under construction (Szabó et al., 2000).

THE KREYBIG SOIL SURVEY

The national soil-mapping project initiated and led by Kreybig was unique being a national, large-scale survey based on field and laboratory soil analysis and in the meantime serving practical purposes (Kreybig, 1937). The aim of the programme was the preparation of a map series „from which those soil properties can be defined directly, which show the physiological conditions of the organisms living in soil and the cultivated plants" (Kreybig, 1938). The practical soil mapping of Hungary was carried out between 1935 and 1951 in more stages. In the early fifties, when the action was successfully completed, Hungary was the first in the world to have such detailed soil information (a total amount of 400 1:25,000 scale map sheets and complementary data in the form of explanatory booklets belonging to each map sheet) for the whole country. These maps still represent a valuable treasure of soil information at the present time.

The soil and land use conditions were shown jointly on the maps. Land use was given in a simplified form, distinguishing: croplands (arable land, orchards, meadow–pasture); temporarily waterlogged areas; forests; lakes, marshes, rivers and settlements. Overall chemical and physical soil properties of the soil root zone featuring soil patches were identified for croplands. Altogether three characteristics were attributed to soil mapping units and displayed on the maps. Further soil properties were determined and measured in soil profiles.

The characteristic of the Kreybig method is that, a representative and further, non-representative soil profiles occurring within the patch are attached to the soil units of the maps. These profiles together give information on the heterogeneity of the area.

Usage of representative profiles in traditional soil survey is a common solution for the linkage of detailed soil properties originating from soil profile description and analysis and the mapping units of crisp soil map representing the pedological variability of land (Leenhardt et al 1994). However using non-representative soil profiles displaying within soil unit, non-mappable heterogeneity of the ground was a unique approach. The surplus information provided by this methodology can be exploited by the new technology provided by GIS.

THE ELABORATION OF KREYBIG DIGITAL SOIL INFORMATION SYSTEM

1st step: Simple conversion of analogue maps and records into digital format

Digital processing of the Kreybig archives started in 1998 integrating the data available at various institutions, in different scale and processing level (Pásztor et al, 2002a). All map sheets were scanned. Vectorization of spatial data (soil units as polygons and soil profiles as points) is carried out by map sheets. The digital processing of the spatial entities and loading of profile database has been progressing independently. At present compilation of the soil spatial pattern is completed for about 65% of the country. Compilation of profile database module is a bit lagging behind.

For the loading of the field data and laboratory analysis of soil profiles included in the explanatory booklets a data loading and control program was developed (Kreybig Point Data Manager). The manager program reaches the database through installed controllers, with a standard Microsoft JET 3.0 interface. In the development of work sheets, the structure of the explanatory note records was used, making data loading easier and decreasing coding errors. The worksheets are logically independent wholes.

2nd step: Formation of a self-consistent system

Having completed geometric and thematic digitization of neighboring sheets they are fitted together solving edge correction, and then they are merged. At the same time a primary desktop reambulation is carried out. This is necessary because of certain discrepancies experienced in processed data. However survey methodology involved edge correlation between neighbouring sheets, still remained unmatching soil patches. The reason of such inconsistencies might be that the available raw map material can be on different level of processing, thus original edge matching efforts vanished in time. Another reason of discrepancies may be attributed to the temporal shift, which can occur between the independent surveys of even close areas mapped on different sheets. The original analogue maps represented individual cartographic products which fact hid these inconsistencies, multiple sheets were rarely used paralelly, and even if this type of problems were detected by certain users, they were neither reported nor used for a general improvement of the map series.

The projection of available map sheets may also differ from sheet to sheet. Since the processing of maps begins with transformation to the appropriate element of a common map system network, this may cause within sheet distortions of the digitized spatial entities. A secondary transformation is carried out for a better fitting using identical points identified both on soil maps and topographical maps or orthophotos available in the targeted projection system.

3rd step: Increasing thematic accuracy within appropriate SDI

Obvious changes in land conditions, which are not accounted for in a SSIS, may stagger the applicability of the whole database even if the mapped soil properties did not change significantly (or generally at all) on the majority of the territory. Integration of spatial soil information within appropriate SDI can help to treat this problem. Reliability and accuracy can be increased by taking into consideration the changes reflected by digitally available recent information on topography and/or land use (remotely sensed images, spatial databases), which are simultaneously used within the same GIS environment. For pilot areas around the country this primary desktop update of the polygon structure was already carried out. CLC100, CLC50, orthophotos and forest cadaster were used for the correction. Finalizing this stage the elaborated Kreybig Digital Soil Information System (KDSIS) can already be regarded as a true SSIS even by more rigorous critics (Rossiter, 2004).

A key issue of applicability of SSISs is their accuracy, since essentially the main practical aim of soil survey and soil maps is prediction (Leenhardt et al., 1994). KDSIS provides two different opportunities for increasing its spatial and thematic accuracy on soil properties.

4th step: Spatial refinement of spatial units integrating Kreybig profile methodology and SDI

The Kreybig survey used representative and non-representative soil profiles occurring within soil patches for the indication of non-mappable heterogeneity of the land. KDSIS integrated with spatial themes on appropriate environmental factors (DEM, orthophotos etc.) can resolve the constraints of traditional mapping. Location of non-representative soil profiles indicates local heterogeneity, which can be frequently identified in terrain, landuse, topography, thus new soil boundaries can be outlined which subdivide the original mapping units. Soil profile accounted for, as non-representative in its former supporting patch becomes the representative profile of the newborn entity. Spatial resolution as well as the accuracy of the overall system can be this way increased. This activity also contributes to the conversion of the single scale KDSIS into a multi-level SSIS with an opening to the larger scales.

5th step: Updating soil information with recent fieldwork

Predominantly the information provided by Kreybig maps is still timely, because the temporal changes in the mapped soil characteristics are not really significant. However field verification/correlation studies completed with appropriate data collection, and the inclusion of newly accessed data into KDSIS can also significantly increase its reliability. This verification should be carried out by the reambulation of the originally mapped areas and the dug profiles accompanied with new samplings at the revisited sites.

The stages of field reambulation are as follows:

- Identification of the representative soil profiles sampled during the Kreybig survey to be revisited taking into consideration all available original information on the survey and recent information on the present status of the sample site.
- Navigation to the location using the opportunities provided by field GIS.
- Testing the accessibility of the location or assignment of new profile location
- Determination of the representativity or assignment of new profile location
- Determination of the acceptability of the site as a new Kreybig profile based on mini profile or test boring or assignment of new profile location
- Detailed soil sampling by diagnostic layers

Integration of traditional pedological knowledge, KDSIS and field GIS makes sampling expedient thus fieldwork becomes quick, efficient and consequently economic. Relatively large regions can be surveyed and characterized by the updated soil properties determined in the revisited or the newly assigned representative profiles whose representative locations are tested and verified in the field. On the other hand, if a detailed soil sampling is carried out within a smaller area (not definitely for the purpose of updating KDSIS) its data content could be also incorporated given the collected soil information is thematically compatible with KDSIS. This latter can be another way toward the multi-level KDSIS.

During its development different stages of KDSIS provides soil information on different level of accuracy. This kind of multilevel feature can be preserved and even utilized. Data on a lower level of development (and consequently less precise) could be produced and serviced faster and sometimes time is more dominant factor than spatial and/or thematic accuracy. For smaller scale application “rawer” data might prove to be sufficient and in the meantime more economic. Deepening KDSIS and extending its more elaborated levels, also involves the opportunity of the estimation of the accuracy expectable on the former levels.

RESULTS AND DISCUSSION

The applicability of KDSIS is simply proved by the fact, that even up till now numerous users were satisfied by the raw or value added data queried from the system, maps produced based on

KDSIS or result achieved by its spatial analysis. Molnár et al. (1999) used KDSIS in habitat mapping. Farkas et al. (2005) used for the regional extension of results of their modelling work on impacts of different climate change scenarios on soil water regime. Rajkai (2005) investigated the applicability of physical soil properties provided by KDSIS for the estimation of more complex hydrological properties of soils. Very recently KDSIS was used as base information source within the various task packages (land management planning, water management modelling in the territories of future water reservoirs etc.) of the Action Plan on Flood Prevention and Protection for the Tisza River (Szabó & Pásztor 2004). The fully loaded KDSIS is suggested to serve as a well-established basis for various further soil related expert systems as well as to be suitable for the foundation of the soil module of the Hungarian SDI.

The new samplings at the revisited sites make the comparison of archived (and so far stored) and newly surveyed data possible. Changes in soil properties can be identified. This in one hand should be recorded in the database thus updating it. On the other hand trends can be identified in soil characteristics and functions, degradation processes can be realized and/or forecasted. It can serve as reference to the study of anthropogenic effects. Spatial extension of the information achieved in point locations (both measured soil features and/or identified changes) can be carried out based on representativity thus making spatial inventory of soil related processes possible.

The overall elaboration and mainly reambulation process of KDSIS cannot be carried out by a single research institute and needs extra-institutional co-operation, but the common concept should be elaborated in advance. Nevertheless the framework of the SSIS and its reambulation methodology was worked out.

BIBLIOGRAPHY

Burrough, P.A., Steps in the Representation of Digital Soil Information: 1976-2004. DSM 2004 Montpellier 13-17 September 2004. Elsevier, 2005.

CEC, Towards a Thematic Strategy for Soil Protection. Brussels, COM(2002) 179 Final. 2002.

CEC, Proposal for a Directive of the European Parliament and of the Council establishing an infrastructure for spatial information in the Community, COM(2004) 516 Final. 2004.

Dusart J., Adapting soil mapping practices to the proposed INSPIRE guidelines. DSM 2004 Montpellier 13-17 September 2004. Elsevier, 2005.

FAO, A framework for land evaluation. FAO Soils Bulletin 32, Rome, 1976.

Farkas Cs., Randriamampianina R., Majercak, J., Modelling impacts of different climate change scenarios on soil water regime of a Mollisol. Cer. Res. Com., 33: 185-188, 2005.

Hubrechts L., Vander Poorten K., Vanclooster M., Deckers J., From Soil Survey to quantitative land evaluation in Belgium. European Soil Bureau. Research Report No. 4.: 91-100, 1998

Kreybig L., 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, 1937.

Kreybig L., General explanation to the soil maps (in Hungarian and German). M. Kir. Földtani Intézet, Budapest. 1938.

Lagacherie P., McBratney A.B., Spatial Soil Information Systems and Spatial Soil Inference Systems: perspectives for digital soil mapping. DSM 2004 Montpellier 13-17 September 2004. Elsevier, 2005.

Leenhardt D., Voltz M., Bornand M., Webster R., Evaluating soil maps for prediction of soil water properties. European Journal of Soil Science, 45(3): 293-301, 1994.

Lim K.J., Engel B.A., Extension and enhancement of national agricultural pesticide risk analysis (NAPRA) WWW decision support system to include nutrients. Computers and Electronics in Agriculture 38: 227-236, 2003.

Mermut A.R., Eswaran, H., Some major developments in soil science since the mid-1960s. Geoderma 100 (3-4): 403-426, 2000.

Molnár Zs., Kun A., Bölöni J., Király G., Az élőhely-térképezés alkalmazása a biodiverzitás monitorozásában. In: Kun A., Molnár Zs. (eds.): Nemzeti Biodiverzitás-monitorozó Rendszer XI. Élőhely-térképezés. Sciencia Kiadó, Budapest, 16-19, 1999.

McKenzie N., Gallant J., Digital soil mapping with improved environmental predictors and models of pedogenesis. DSM 2004 Montpellier 13-17 September 2004. Elsevier, 2005.

Nachtergaele F., van Ranst E., Qualitative and Quantitative Aspects of Soil Databases in Tropical Countries. In "Evolution of Tropical Soil Science: Past and Future", 2002.

Pásztor L., Suba Zs., Szabó J., Várallyay Gy., Land degradation mapping in Hungary, In: J.F.Dallemand, V. Perdigao (eds.) EUR 18050 – PHARE Multi-Country Environment Programme MERA Project Proceedings, European Comission: 43-54, 1998.

Pásztor L., Szabó J., Bakacsi Zs., Compilation of a national 1:25,000 scale digital soil information system in Hungary, In: Proceedings of the 17^{h} World Congress of Soil Science, Bangkok, 14-22/8/02, CD-ROM, 2002a.

Pásztor L., Szabó J., Bakacsi Zs., GIS processing of large scale soil maps in Hungary, Agrokémia és Talajtan, 51: 273-282, 2002b.

Rajkai K., Estimating hydrophysical properties of soil using KDSIS (forthcoming).

Rossiter D.G., Digital soil resource inventories: status and prospects. Soil Use & Management 20(3): 296-301, 2004.

Szabó J., Pásztor L., Bakacsi Zs., Zágoni B., Csökli G., Kreybig Digital Soil Information System (Preliminaries, GIS establishment), Agrokémia és Talajtan, 49: 265-276, 2000.

Szabó J., Compilation of a watershed level, complex land information system for internet service, Agrokémia és Talajtan, 51: 283-292, 2002.

Szabó J., Pásztor L., GIS-based refinement of the "DKSIS" spatial soil information system in the Bodrogköz region. Proceedings of the 5th International Conference on Influence of anthropogenic activities on water regime of lowland territories; 2004 May 25-27, CD-ROM (ISBN 80-89139-04-3). Michalovce, 2004.

Thwaites, Soil maps-simple information tools or complex decision aids? Australian Association of Natural Resource Management Volume 2 Number 1, 1999.

Várallyay Gy., Soil survey and soil monitoring in Hungary. European Soil Bureau. Research Report No. 9.: 139-149, 2002.

Várallyay Gy., Molnár E., The agro-topographical map of Hungary (1:100,000 scale). Hungarian Cartographical Studies. 14th World Conference of ICA-ACI, Budapest: 221-225, 1989.

Várallyay G., Pásztor L., Szabó J., Michéli E., Bakacsi Zs., Soil vulnerability assessments in Hungary, In: N.H. Batjes, E.M. Bridges (eds.) Soil and Terrain Database, Land Degradation Status and Soil Vulnerability Assessment for Central and Eastern Europe, FAO Land and Water Digital Media Series 10, CD-ROM, FAO, 2000.

Walter C., Lagacherie P., Follain S., Integrating pedological knowledge into soil digital mapping. DSM 2004 Montpellier 13-17 September 2004. Elsevier, 2005.

Webster R., Soil resources and their assessment. Phil. Trans. R. Soc. Lond B 352: 963-973, 1997.

Zhu A.X., Hudson B., Burt J., Lubich K., Simonson D., Soil mapping using GIS, expert knowledge, and fuzzy logic. Soil Science Society of America Journal, 65: 1463-1472, 2001.