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Endre Dobos

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The soil types of the modernized, diagnostic based Hungarian Soil Classification System and their correlation with the World reference base for soil resources

Erika MICHÉLI[1], Ádám CSORBA[1], Tamás SZEGI[1], Endre DOBOS[2] and Márta FUCHS[1]

Abstract

The traditional genetic-based Hungarian Soil Classification System (HSCS) was elaborated during the 1960s. The concept and the units were developed before sufficient data and modern data processing tools became available. The 39 soil types were defined as group of soils developed under similar soil forming factors and processes, resulting in similar morphogenetic properties. The allocation of soils in the system included some subjective elements, even with substantial knowledge and experience of the classifier. The modernized "diagnostic" system was developed based on the accumulated data and experiences with the genetic system as well on the application of new pedometric tools. The definitions and limits of the diagnostic categories (horizons and properties) correspond with the World reference base for soil resources (WRB), but are not identical, they are much simpler, and adopted for the environmental setting of the Carpathian Basin. The 15 soil types (central units) are defined by the newly introduced classification key, based on diagnostic criteria, assuring a more objective result of the classification process. This paper is presenting the rational of the diagnostic system, gives a summary description of the 15 new soil types and discusses the successful correlation with the (WRB).

Keywords: soil classification, genetic approach, diagnostic approach, World Reference Base for soil resources (WRB), correlation

Introduction

In the past few decades the understanding of the global nature of environmental problems created a need for international, harmonized maps and database. The long-term target is a global classification system (Hempel, J. *et al.* 2013; Michéli, E. *et al.* 2016; Hughes, P. *et al.* 2017), however, for the time being, correlation of the units of national systems is essential. Most international databases, maps and related publications, including the European Soil Database (ESDB) (Panagos, P. 2006) and the Soil Atlas of Europe (Jones, A. *et al.* 2005) are based on the World reference base for soil resources, the accepted correlation tool for soil scientists (IUSS Working Group WRB, 2006). Since most systems have their own principles and definitions, simple one to one translation of national units to the WRB is not possible. Generally, reclassification of original data, expert knowledge and, or pedometric applications (mostly taxonomic distance calculations) are applied for the correlation (Minasny, B. *et al.* 2009; Láng, V. *et al.* 2010).

The traditional genetic-based Hungarian Soil Classification System (HSCS) was elaborated during the 1960s. The concept and the units were developed before sufficient data and modern data processing tools became available. The 39 soil types were defined as group of soils developed under similar soil forming factors and processes, resulting in similar morphogenetic properties

[1] Department of Soil Science and Agrochemistry. Szent István University, H-2100 Gödöllő, Páter K. u. 1. E-mails: micheli.erika@mkk.szie.hu, csorba.adam@mkk.szie.hu; szegi.tamas@mkk.szie.hu, fuchs.marta@mkk.szie.hu
[2] Institute of Geography and Geoinformatics, University of Miskolc. H-3515 Miskolc, Egyetemváros. E-mail: ecodobos@uni-miskolc.hu

(Stefanovits, P. 1963; Szabolcs, I. 1966). The allocation of soils in the system included some subjective elements even with substantial knowledge and experience of the classifier. Michéli, E. *et al.* (2006) reported also correlation problems of certain units with international standards. The modernized "diagnostic" system was developed based on the accumulated data and experiences with the genetic system as well on applications of new pedometric tools (Fuchs, M. *et al.* 2011; Láng, V. *et al*. 2013; Michéli, E. *et al.* 2014). The definitions and limits of the diagnostic categories (horizons, properties and materials) are based on stronger and numerical criteria than the previous system. Although the categories are not identical with, but most of them correspond with the World reference base for soil resources (WRB) (IUSS Working Group WRB, 2015). Furthermore, the definitions are, much simpler (as simplicity was among the principles of the modernization) and adopted for the environmental setting of the Carpathian Basin. The new 15 soil types are defined by the newly introduced classification key, based on the diagnostic criteria, assuring a more objective result of the classification and correlation processes (Michéli, E. *et al.* 2014). In this paper we provide and discuss the correlated WRB units for the soil types of the modernized, diagnostic-based Hungarian Soil Classification System to help better communication and data exchange on international forums.

Materials and methods

The methods of the modernization efforts of the Hungarian Soil Classification System included: linking the processes to diagnostics (Michéli, E. *et al.* 2011), review and pedometric evaluation of the taxonomic relationships of the genetically defined units (Fuchs, M. *et al.* 2011; Láng, V. *et al*. 2013), the development of the new central units (15 soil types), the development of the classification key, and the definition of the methodology to derive the lower level (subtype and variety) units. The 15 new soil types are the result of merging similar genetic soil types and introducing new soil types, not existing in the genetic system (Michéli, E. *et al.* 2014).

The current official correlation system and the tool for development of harmonized soil information products is the WRB 3rd edition (IUSS Working Group WRB, 2015). On the highest level 32 reference soil groups (RSG) are distinguished and defined by the key, based on the required diagnostic criteria. The RSG level was applied for the correlation of the HSCS soil types. The lower level combinations with the qualifiers are countless and are not in the scope of the present paper. For the definition of the correlated HSCS soil types with the WRB RSGs, simple reviews, expert knowledge and in some cases pedometric tools were applied (Láng, V. *et al.* 2010; Michéli, E. *et al.* 2016).

Results and discussion

The simplified classification key for the 15 soil types and the most likely correlated WRB RSGs are given in *Figure 1.* (The HSCS soil type names are written in bold.) For the correlated WRB RSGs the most likely correlated unit is given. Additional less common options are given in bracket. Short discussion for the correlation of each soil type is coming below.

Peat soils

Peat soils of Hungary are organic soils that commonly developed in local water-logged depressions. As a result of long-term water saturation undecomposed or partially decomposed biomass of the wetland habitats has been accumulated. In higher altitude locations, with cool climate, the peat material may consist of undecomposed moss fibres. The defined thickness (≥ 40 cm), depth (starts from 40 cm from the surface) and organic carbon content (OC ≥ 20%) are criteria of the organic layer(s), provide easy correlation with the *WRB Histosols*. Peats overlying ice, or

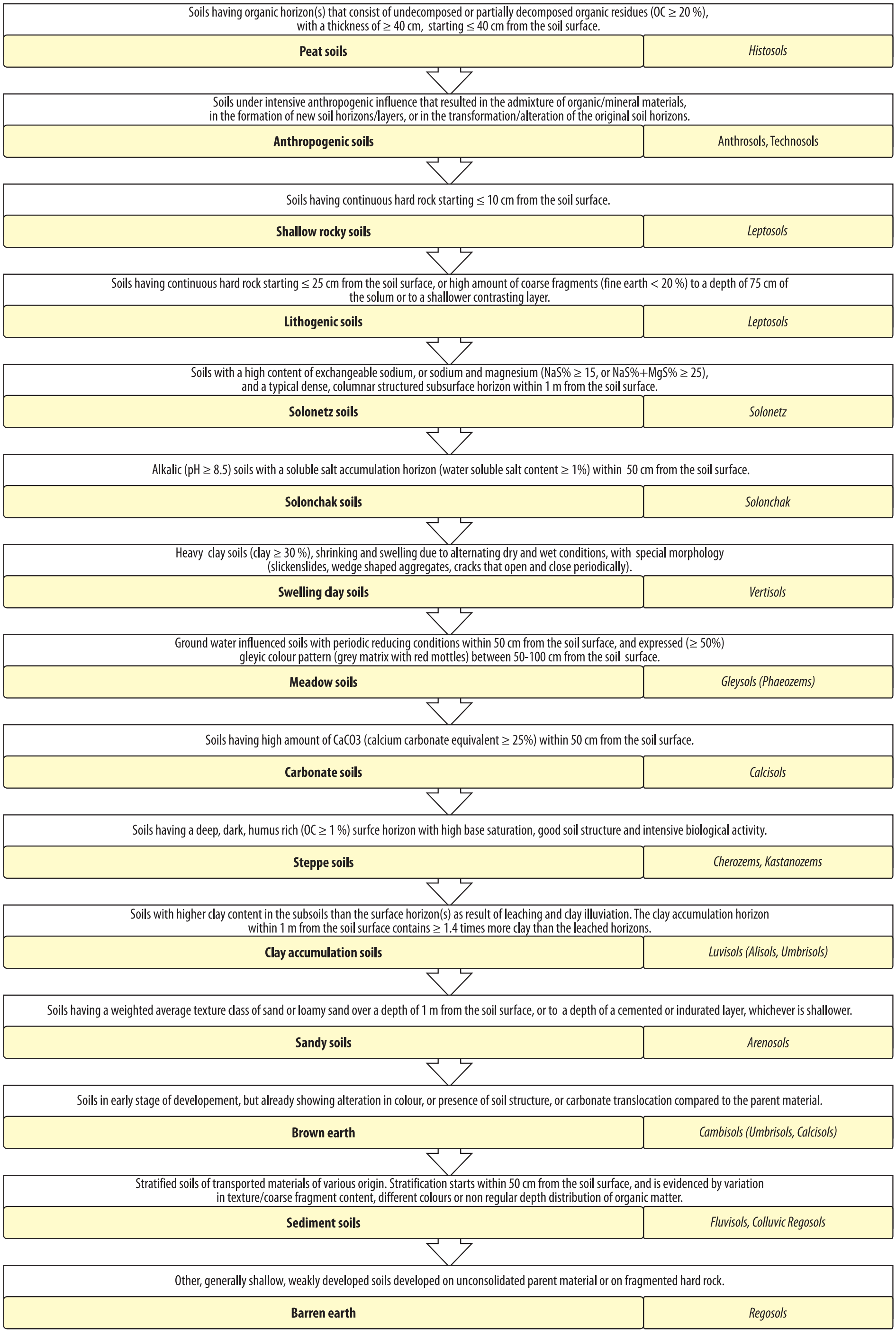

Fig. 1. The simplified classification key for the 15 soil types of the modernized, diagnostic based HSCS and the most likely correlated WRB (2015) RSGs.

continuous hard rock are not documented in Hungary, hence such situations are not part of the definition of peat soils and have no relevance for correlation with the WRB shallow Histosol options (criterion 1. in the WRB key).

Anthropogenic soils

The group of anthropogenic soils is a newly introduced soil type in the modernized HSCS. The soil type combines soils under intensive anthropogenic influence that resulted in the admixture of organic/mineral materials (> 20%), in the formation of new soil horizons/layers, or in the transformation/alteration of the original soil horizons within 100 cm from the soil surface. The HSCS Anthropogenic soils may correlate with the *Anthrosols* and/or *Technosols* reference soil groups of WRB. The precise correlation, however, is only possible with the application of the qualifiers in both systems (eg. Terric, Linic etc.). Farsang, A. *et al.* (2015) contributed to the development of the concept and definitions of the anthropogenic soils. Since these soils were not part of the traditional Hungarian system, experiences with application are limited.

Shallow rocky soils

Typical soils of the steep, highly eroded surfaces of mountainous regions of Hungary, where continuous hard rock is starting ≤ 10 cm from the soil surface, and rock outcrops are common. The depth criteria provide a one-to-one correlation with *Lithic* or *Nudilithic* "versions" of the WRB *Leptosols*. Since these soils occupy less than 0.5 per cent of the country it is considered to combine them with the Lithogenic soils of the HSCS.

Lithogenic soils

Lithogenic soils include the Rendzinas, Rankers and Erubase soils of the former genetic system (Stefanovits, P. 1963), in which no specific depth criteria are defined. The modified definition of these shallow, rocky soils fully corresponds with the WRB *Leptosols* definition (having continuous hard rock, starting ≤ 25 cm from the soil surface; or high amount of coarse fragments (fine earth < 20%) over a depth to 75 cm or to the bedrock). The traditional names are preserved on the lower level of the classification with the application of the subtype qualifiers.

Solonetz soils

Both Solonetz and Solonchak soils are typical for lowland areas with high evaporation rate. Their characterization, classification and mapping have long traditions in Hungary, and the achievements of Hungarian scientists influenced the classification of salt-affected soils globally (Szabolcs, I. 1989; Tóth, T. and Várallyay, G. 2002). Solonetz soils are defined by the presence of high amount of adsorbed sodium and/or magnesium, and the strongly structured columnar subsurface horizon. In the WRB the natric horizon is defined on 2 pages with several alternatives and sub-criteria. The HSCS has a simplified definition, however, the criteria for the exchangeable sodium percentage ESP ≥ 15, or Na + Mg > 25 per cent, and the similar morphological criteria provides easy correlation with the WRB *Solonetz* soils.

Solonchak soils

Solonchaks are alkaline (pH ≥ 8.5) soils with high accumulation and concertation of soluble salts at, or close to the surface. Due to the limited biological activity and bioturbation, Solonchaks show moderate genetic horizon development in the subsoil. The original stratification of the fluvial or lacustrine sediments is commonly preserved. The criteria for the salt accumulation horizon (water soluble salt content ≥ 1% within 50 cm from the soil surface) is defined by using the standard Hungarian unit for salt content, but with the application of a conversion factor developed by Filep, G. (1999) successful correlation with the WRB *Solonchak* RSG is possible. Soils that do not meet the salt criterion, hence the EC requirement may correspond with other WRB RGSs (eg. *Gleysols* or *Fluvisols*), however, the salt accumulation can be indicated with the *Protosalic* (EC ≥ 4 dS/m) qualifier in the correlation.

Swelling clay soils

"Swelling clay soils" are newly introduced to the modernized HSCS. They may form in different landscapes from fluvial depositions to mountain pediments and were allocated in different genetic soil types (alluvial soils, meadow soils, "erubaz" soils (soils of volcanic origin), however, the common characteristics are the high clay content (≥ 30%), and shrinking and swelling properties due to alternating dry and wet conditions. The corresponding criteria for the clay content and for the special morphology (slickensides, wedge shaped aggregates, cracks that open and close periodically) within 1 m from the soil surface, provide a one-to-one correlation with the *Vertisols* RSG of the WRB.

Meadow soils

The genetically defined "meadow soils" are groundwater-affected soils of lowland areas with redoximorphic features (Stefanovits, P. 1963; Szabolcs, I. 1966). However, the lack of the criteria for depth and expression for the colour patterns allowed subjectivity in the classification and correlation process. With the introduction of the definition of reducing condition, the gleyic colour pattern and depth criteria, correlation with WRB is easier. Meadow soils with periodic reducing conditions within 50 cm from the soil surface, and evidences of the gleyic colour patterns in more than 50 per cent of the matrix between 50–100 cm from the soil surface likely correlate with the WRB *Gleysols*. Other groundwater influenced soils with deeper redoximorphic features may correspond with other WRB RSGs but can be specified with the *Gleyic* qualifier in the correlation process.

Carbonate soils

Carbonate soils are also new in the modernized HSCS. These soils have high amount of $CaCO_3$ (calcium carbonate equivalent ≥ 25%) within 50 cm from the soil surface. This high amount of mostly secondary carbonates have generally weathered or have been leached from the primary parent material (i.e. from limestone, loess, marl). The secondary accumulation of carbonates is often combined with erosion ("bringing" accumulations close to the surface). Significant part of Hungary is a carbonate rich basin, where carbonate soils can develop in various soil forming environments from hill sediments to eroded loess plateaus. Since the amount and the depth criteria of carbonates of the HSCS Carbonate soils are much stronger than the WRB Calcisols, the correlation is not straight forward. Most HSCS Carbonate soil fulfil the requirements of the WRB Calcisols, however, only a portion of WRB *Calcisols* correspond with the HSCS Carbonate soils.

Steppe soils

The traditional Dokuchaev Chernozem concept (Dokuchaev, V.V. 1883) influenced most genetic-based national classification systems. As result of substantial surveys, new knowledge, as well as degradation processes, changes occurred in the classification of the deep, dark steppe soils (soils developed under grassland vegetation). In the WRB four RSGs are dedicated to soils with high organic matter content in the dark mineral surface soils: The *Chernozems* and *Kastanozems* (secondary carbonate present at shallow depths), the *Phaeozems* (secondary carbonate leached to a depth ≥ 50 cm below the organic matter-rich mineral top horizon) and the low base *Umbrisols*. In the Carpathian Basin most of the Steppe soils formed on loessy parent material and have deep, dark OC reach surface horizons and subsurface horizons with secondary carbonates. The criteria of the humus-rich surface horizon corresponds with that of the WRB mollic horizon in terms of depth (20 cm), colour (Munsell chroma ≤ 3), base saturation (≥ 50%), and favourable structure, however, based on the statistical studies of national data sets (Láng, V. 2013), in the classification key of the diagnostic based HSCS stronger criteria was set for OC content (≥ 1%) for the Steppe soils, similarly to WRB chernic horizon for the Chernozems. This allows satisfactory correlation of the HSCS unit with the lighter coloured WRB *Kastanozems* and the darker *Chernozems*. The close taxonomic relationship is evident, however, not all WRB *Kastanozems* and *Chernozems* satisfy the HSCS Steppe soil criteria – as in the HSCS key the presence of > 20 per cent coarse fragments to 50 cm depth, or continuous rock or clay accumulation horizon within 1 m are also excluded from Steppe soils. As these soils represent the most fertile soils of Hungary (Várallyay, G. *et al.* 1985) further fine-tuned studies are going on for nomenclature (the Steppe soil name is not satisfactory for the authors) and the lower level specifications.

Soils with clay accumulation

In the traditional genetic approach clay accumulation soils were listed among the brown forest soils in many countries, at the same time other members of brown forest soils were often confused with clay accumulation soils (Cline, M.G. 1949; Tavernier, R. and Smiths, D.G. 1957). In most modern soil classification systems clay accumulation soils are representing individual classes and do not preserve forest related nomenclature. In the modernized diagnostic based HSCS the criteria for the presence of the clay accumulation horizon is corresponding with WRB *argic* horizon in terms of depth (within 1 m) of the clay enriched horizon and clay increase (1.4% × compared to the leached horizons) and the requirements of clay skins in case of truncated, ploughed or polygenetic soils (with lithological differences). This allows an easy correlation of the HSCS Clay accumulation soils with the *Luvisols* of the WRB. In forested areas where clay accumulation soils develop deep, high OC containing surface horizons, they may correlate with the WRB *Umbrisols*. In limited areas where the acidification processes are intensive and the effective base saturation of the clay accumulation horizon is < 50 per cent, the *Alisols* RSG may be the corresponding WRB unit.

Sandy soils

Sandy soils of Hungary are typically weakly developed soils, have low amount of organic and inorganic colloids, which resulted in unfavourable physical-, chemical properties and low fertility. These soils have a weighted average texture class of sand or loamy sand to a depth of 1 m from the soil surface, or to a depth of a cemented or indurated layer, whichever is shallower. These criteria are fully matching the WRB *Arenosols* reference group, providing an easy correlation. In cases when sand is covering other soils or layers with contrasting texture, correlation is more complicated and requires decisions based on the specific situation.

Brown earths

Brown earth was the other typical member of brown forest soils in the genetic based system (Stefanovits, P. 1963; Szabolcs, I. 1966). However, the insignificant subsurface horizonation may develop in different soil forming environment (Jenny, H. 1941; Cline, M.G. 1949; Tavernier, R. and Smiths, D.G. 1957). Hence in the WRB and most other systems soils showing slight alteration in colour and soil structure compared to the parent material are listed as separate units on the highest level of classification. Although the definition of Brown earths is corresponding with the *Cambisols* reference group of WRB, correlation might be a problem. The cause of the problem is the definition of the *Calcisols* and their position in the key, before the *Cambisols*. If a Brown earth of the HSCS has a calcic horizon (carbonates ≥ 15%) within 1 m (which is often the case, especially in eroded landscapes), they key out as a *Calcisols* RSG. The problem with the *Calcisol* definition and position in the key have been reported problematic in other countries as well and need to be reviewed by the WRB Working Group of IUSS.

Sediment soils

Sediment soils include soils with the presence of stratification within 50 cm from the soil surface as a result of accumulation of transported materials of various origin. Thus, the soil material of sediment soils was not developed in-situ, but transported and redeposited by erosion, or by fluvial or lacustrine processes. The stratification is required to be evidenced by the variation in texture/coarse fragment content, different colours or by not regular depth distribution of organic matter, or by the presence of a layer with 0.2 per cent higher OC content than the overlying layer within 1 m. These criteria are providing a satisfactory correlation of Sediment soils of the diagnostic based HSCS with corresponding *Fluvisols* or *Colluvic Regosols* of WRB. Problematic situations may occur when the sediment have a calcic horizon (as described at the Brown earth discussion). In such cases the Sediment soils key out as Calcisols, which is not a satisfactory correlation in terms of taxonomic relationships (or similarities).

Barren earths

Other soils, that do not satisfy the requirements of any other soil type of the HSCS, thus, key out at the end of the classification key as Barren earth. Barren earths are generally shallow, weakly developed soils on unconsolidated parent material or on fragmented hard rock, usually on highly eroded or on very young surfaces. Barren earths correspond with the WRB *Regosols*.

WRB reference groups that do not occur in Hungary

Out of the 32 RSGs 20 are relevant in the Carpathian Basin. The WRB reference groups that do not occur in Hungary are mostly related to climatic or parent material differences. The below statement may be reviewed, if new surveys or investigations provide evidences of presence of the listed RSGs.

Cryosols are soils of the permafrost environment, hence only paleo (mostly buried) soils have fossil cryogenic features (Berényi Üveges, J. *et al.* 2003).

Andosols are soils developed from fresh glass-rich volcanic ejecta. Soils developed from volcanic parent material in Hungary are substantially weathered and developed, consequently, no Andosols have been documented in Hungary (Madarász, B. 2005).

Podzols are very acidic soils developing mostly under boreal forests. The criteria for the subsurface accumulation of iron and aluminium with or without organic matter are very strong in the WRB. National inventories do not include pedons that correspond with the WRB Podzols criteria (Láng, V. 2013). Local formations with limited extent, however, might be possible.

Plinthosols, Nitisols and Ferralsols are highly weathered soils of the tropics, and do not develop under the current climate of Hungary. Although paleo features of such soils have been documented by Fekete, J. *et al.* (2006).

Planosols and Stagnosols are related to long term water logging and textural differentiation. Stagnic features are common mostly in the HSCS Clay accumulation soils and the Swelling clay soils, but pedons developing the required expression of the features are likely to occur, but were not documented.

Durisols are silica cemented soils of old arid and semi-arid areas and up till now, even paleo Durisols have not been documented in Hungary.

Gypsisols are gypsum accumulation soils. Although gypsum is common in Solonetz and Solonchak soils and the *Gypsic* qualifier is an option to indicate the feature.

Retisols are typical for ice-age influenced soils with coarse bleached interfingering material into a clay rich subsurface in a net-like pattern. So far, no pedon with the feature has been documented.

Acrisols and Lixisol are clay accumulation soils of old surfaces, with low (≤ 24 cmol/kg) cation exchange capacity (CEC) of the clay. In Hungary the mineralogy of clay accumulation soils is characterized with much higher CEC (Stefanovits, P. 1963) and so far, no *Acrisols* or *Lixisols* were documented.

Preserving legacy semantic and spatial soil information

With the application of a computer assisted algorithm the earlier genetic classification units can be converted to the new ones, preserving the value of the legacy soil information (Láng, V. 2013; Michéli, E. *et al.* 2014). The geographical distribution of the soil types of the modernized diagnostic-based HSCS is a greater challenge, as often no analytical data is supporting the spatial patterns. However, with the application of pedometric and digital soil mapping tools promising methodologies were documented by Dobos, E. *et al.* (2014) and Pásztor, L. *et al.* (2018) which can be adopted for the development of new national maps and correlated internationally understood maps.

The next and perhaps the most crucial test of the system is to map the new soil types (central units) and diagnostic categories and analyse their spatial patterns and their relationships with the physical geographic conditions of Hungary. An automated classification algorithm was developed to derive the classification units from legacy databases. With the application of the legacy data and new georeferenced field observations the spatial definition of new units is possible. This work is going on and will be subject of a follow up paper.

Conclusions

The 15 soil types defined in the diagnostic based, a modernized Hungarian Soil Classification System (HSCS) were developed based on the accumulated data and the genetic system. The introduced diagnostic approach with stronger morphogenetic and numerical criteria are not identical but correspond with the criteria of the classification units of the World reference base for soil resources. Although there are only few cases when one to one matching is possible, the adopted numerical criteria provide successful correlation results. Updating the national database and maps and the relevant correlated products is a challenge that needs substantial effort, however, promising methodologies have been documented.

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Citizen observatory based soil moisture monitoring – the GROW example

Károly Zoltán KOVÁCS[1], Drew HEMMENT[2], Mel WOODS[3], Naomi K. van der VELDEN[4], Angelika XAVER[5], Rianne H. GIESEN[6], Victoria J. BURTON[4], Natalie L. GARRETT[7], Luca ZAPPA[5], Deborah Long[3], Endre DOBOS[1] and Rastislav SKALSKY[8]

Abstract

GROW Observatory is a project funded under the European Union's Horizon 2020 research and innovation program. Its aim is to establish a large scale (more than 20,000 participants), resilient and integrated 'Citizen Observatory' (CO) and community for environmental monitoring that is self-sustaining beyond the life of the project. This article describes how the initial framework and tools were developed to evolve, bring together and train such a community; raising interest, engaging participants, and educating to support reliable observations, measurements and documentation, and considerations with a special focus on the reliability of the resulting dataset for scientific purposes. The scientific purposes of GROW observatory are to test the data quality and the spatial representativity of a citizen engagement driven spatial distribution as reliably inputs for soil moisture monitoring and to create timely series of gridded soil moisture products based on citizens' observations using low cost soil moisture (SM) sensors, and to provide an extensive dataset of *in situ* soil moisture observations which can serve as a reference to validate satellite-based SM products and support the Copernicus *in situ* component. This article aims to showcase the initial steps of setting up such a monitoring network that has been reached at the mid-way point of the project's funded period, focusing mainly on the design and development of the CO monitoring network.

Keywords: citizen science, citizen observatory, crowdsourced data, soil moisture monitoring

Introduction

Environment-related pressure on our society is intense. The attentive use and management of environmental resources are crucial for future generations' prosperity. Better observation, understanding, protection, and enhancement of our environment is only feasible with the active involvement of citizens. Although our political, economic and administrative structures may be designed to tackle our environmental concerns through scale and strategic decisions, citizens often feel as though they are un-engaged, silent observers (McGlade, J. 2009; Liu, H.Y. *et al.* 2014). Formal institutions like EU Water Framework Directive, Flood Risk Directive and

[1] Institute of Geography and Geoinformatics. University of Miskolc. H-3515 Miskolc, Egyetemváros. E-mails: ecocares@uni-miskolc.hu, ecodobos@uni-miskolc.hu
[2] University of Edinburgh, E-mail: drew.hemment@ed.ac.uk
[3] University of Dundee. E-mails: m.j.woods@dundee.ac.uk, d.long@dundee.ac.uk
[4] Permaculture Association (Britain). E-mails: naomi@permaculture.org.uk, victoria@permaculture.org.uk
[5] Department of Geodesy and Geoinformation, TU Wien, Gußhausstraße 27–29, 1040 Wien, Austria. E-mails: angelika.xaver@geo.tuwien.ac.at, luca.zappa@geo.tuwien.ac.at
[6] HydroLogic Research, Delft, The Netherlands, rianne.giesen@hydrologic.com
[7] Met Office, United Kingdom, natalie.garrett@metoffice.gov.uk
[8] International Institute for Applied Systems Analysis, Laxenburg, Austria skalsky@iiasa.ac.at

the Aarhus Convention require citizen participation. Despite the long history of 'Citizen Observatory' (CO) quality assurance for the scientific use of citizen science generated data is still missing (Freitag, A. *et al*. 2016). Nevertheless, robust examples exist, such as, The National Audubon Society Christmas Bird Count which has been running since 1900 in North America, the data collected by observers over the past century allow researchers, conservation biologists, wildlife agencies and other interested individuals to study the long-term health and status of bird populations across North America (Butcher, G.S. *et al.* 1990; Hochachka, W.M. *et al.* 2012).

The chosen subject of observation itself has an influence on how successful a citizen observatory will be. Examining the motivations of citizen science participants can give insights into why certain initiatives are more successful than others (Clary, E.G. and Snyder, M. 1999; Rotman, D. *et al.* 2012; Geoghegan, H. *et al.* 2016). Citizen science projects are dominated by biodiversity topics rather than the abiotic environment (Pocock, M.J.O. *et al.* 2017), possibly because experiencing and improving the environment is a common motivator of citizen observations (West, S.E. 2015). Weather and climate is also a popular topic (Gharesifard, M. *et al.* 2017) because this has an impact on citizens' everyday life. Sufficient data and validation have been collected to initiate commercial applications for citizen observation data in weather forecasts.

The GROW Observatory monitors soil properties, aiming to engage a target audience of smallholders, and community groups practicing sustainable growing. The participants' motivation is mostly focussed on: improving their immediate environment; growing crops; getting the most out of their land through sustainable practices, without harming the environment and concerns about soil degradation. Emotional motivation is evident for the stakeholders, but to engage and train participants to generate an observation dataset of high scientific standards poses challenges. GROW Observatory during the funded period of the project aims to organize a CO, which is viable after the funded period. To engage and train core groups of stakeholders all over Europe is a must to reach this goal. The first half of the project was to establish the framework, develop the training and communication tools and strategies, to define and engage communities around Europe.

As soil formation is slower than the human-induced degradation processes, it can be considered a non-renewable or a conditionally renewable resource. To sustainably manage soils over a large geographic scale, sophisticated environmental monitoring infrastructure is required and society of environmentally conscious citizens. By the continuous observation and documentation of our environmental conditions, both regular individuals and scientists can learn the impact of the related activities. Awareness raising is one of the most important goals of the GROW Observatory project.

The soil has various physical, chemical and biological properties, which define its ability to support its functions. Soil moisture is the amount of water present in the soil. It defines the thermal buffering capacity of warming and cooling the environment, the amount of available water for biomass production. Soil is a reservoir of a significant amount of continental freshwater from the water cycle as well. Soil moisture is an ever-changing property of the soils. It is influenced by climate, soil texture and structure, organic matter content and above all land use and land-cover (Várallyay, G. 1989). Detailed observation of the spatial and temporal distribution and variation of soil moisture is fundamental for drought and flood modelling, global climate predictions or the precise use of agricultural land (Várallyay, G. 2010). Soil moisture serves as a key input parameter in wind and water erosion estimations and is a driving parameter of soil biological activity and diversity, organic matter development, hence carbon sequestration (Lavelle, P. *et al*. 2006). One of the biggest threats to agricultural land is soil compaction and soil moisture is a principal parameter influencing soil strength, so it is a particularly helpful characteristic when assessing the likely magnitude of the soil shearing resistance and hence the inherent vulnerability of subsoil to compaction. Long term soil moisture measurements describe the soil moisture regime, which defines salinization processes on salt-affected soils. For these reasons and more, it is extremely important for soil moisture to be measured.

In situ measurements have been historically used as the main source of information on local moisture conditions (Várallyay, G. 1994; Makó, A. *et al.* 2010). Several techniques have been developed for measuring *in situ* soil moisture, each having specific advantages, characteristics and measurement accuracy (Robinson, D.A. *et al.* 2008; Dorigo, W.A. *et al.* 2011b). The most commonly used instruments measuring soil moisture over a small area which hence were the only representative of the conditions a few centimetres around the sensor. Even though a large number of local and regional soil moisture networks are operating worldwide, they lack common standards (e.g. observed variables, sensor types, sensor setup, etc.) and the generated data are often not freely available. The International Soil Moisture Network (ISMN, https://ismn.geo.tuwien.ac.at/) (Dorigo, W.A. *et al.* 2011a, b) is an international initiative trying to overcome such issues. *In situ* soil moisture observations are collected from various networks distributed all over the globe, harmonized in terms of the sampling interval, units, and data format and made freely available to the public through a web portal (IPCC, 2007). In Europe, there are fewer than 250 stations available in the ISMN providing information about the water content of the soil. It is, therefore, evident that there is great potential offered by COs (e.g. GROW) to contribute with an unprecedented stream of data from thousands of sensors. Nevertheless, European-wide and global analysis based on ground observations would remain challenging because such measurements are spatially sparse. Due to the high spatial variability of soil moisture, a huge number of stations would be necessary. However, the high costs related to installation, operation and maintenance of the sensors, as well as the limited accessibility of certain regions, make the setup of such a network not feasible (Gruber, A. *et al.* 2013).

To fill this gap, remotely sensed data from optical/thermal and microwave instruments are being used to retrieve soil moisture globally (Wang, L. and Qu, J.J. 2009). In particular, microwave sensors, both active and passive, have proven successful for estimating dielectric properties of soil, thus, leading to the estimation of soil moisture (Mohanty, B.P. *et al.* 2017). Furthermore, when compared to optical/thermal sensors, microwave remote sensing has the great advantage of observing the Earth's surface independently from the weather (i.e. cloud cover) and solar conditions (i.e. both during day and night). Several satellite-derived datasets have been available for the last two decades, providing long-term records of global soil moisture conditions. The use of coarse-scale observations (10–50 km) from active or passive sensors is well established and used for operational purposes. For example, remotely sensed soil moisture products from the Advanced Scatterometer (ASCAT) aboard Metop (Wagner, W. *et al.* 2013), the Soil Moisture and Ocean Salinity (SMOS) (Kerr, Y.H. *et al.* 2012) and Soil Moisture Active Passive (SMAP) (Chan, S.K. *et al.* 2016) missions have been extensively evaluated and found widespread use (Grainger, A. 2017; Bauer-Marschallinger, B. *et al.* 2018).

However, such coarse scale products do not meet the requirements of many applications, such as irrigation management, erosion/landslide prediction, and catchment-scale hydrologic processes. The recently launched Sentinel-1 mission is scanning the Earth's surface at unprecedented spatial resolution (backscatter retrieved at 20 m). In particular, Sentinel-1 is a mission of the European Earth observation program Copernicus, consisting of two identical satellites, Sentinel-1A and Sentinel-1B, launched in April 2014 and April 2016 respectively, and carrying a Synthetic Aperture Radar (SAR) system. The soil moisture retrieval from Sentinel-1 poses some challenges because of the complex influence of terrain roughness and vegetation on the backscattered signal and is, therefore, available at a 1 km spatial resolution (Bauer-Marschallinger, B. *et al.* 2018). This product is currently in preparation for operational dissemination through the Copernicus Global Land Service (https://land.copernicus.eu/global/products/ssm). Regardless of the sensor used to estimate soil moisture, satellite-derived products are becoming more and more valuable for local to global monitoring of the Earth status. The calibration of algorithms and validation of products are of vital importance, therefore, so too are spatially distributed *in situ* monitoring networks providing long-term reference measurements (Mohanty, B.P. *et al.* 2017).

The GROW Observatory aims to demonstrate a CO can deliver widespread uptake, robust science, societal impact, and by prototyping new innovative services, be a sustainable business model for long-term operation. Citizens' Observatories are a concept developed at the European Union (EU) level. COs are communities of stakeholders which include citizens, scientists, policymakers and others collaborating on research, and in this case for environmental monitoring, whose issues have impacts related to land cover and land use. A soil moisture participatory monitoring network is a step forward in environmental monitoring. A European-wide network of stakeholders interested in the state of soil on local, regional, national and EU level generates not only data and other observations but also discussion and knowledge-sharing related to soil protection, land use, soil conditions, and climate monitoring, documentation on growing practices and harvest data. The basis for the professional and scientific framework of the dialogue of participants of the CO is provided by the widespread and accurate communication and training materials, face-to-face workshops. The value of the common knowledge generated by the CO is worth as much for the community as much the generated quality data is important for science.

Methods and procedure

Functional citizen observatories can take a number of routes to development, many are bottom-up initiatives developing organically to address a matter of environmental concern, with an initial momentum. To address the specific scientific needs, the GROW Observatory is taking the example and top-down organizes a soil moisture citizen-based monitoring network. Demand exists for the science part, and for part of professional land users also, the formulation of the real return value is still a must.

The GROW Observatory set out to demonstrate a complete 'Citizens' Observatory' system for monitoring SM, land use and land-cover, contributing *in situ* data for satellite validation, creating useful data products and applications, and overcoming barriers to uptake. GROW entails a particular approach to mobilizing citizens and stakeholders from science and policy in data collection, data awareness, and data innovation. This approach was described and formalized in the first year of the project as a framework, in order that it can be effectively developed, evaluated and replicated. The GROW citizens' observatory framework is here proposed as a process model underpinned by four cross-cutting values. Together these documents an ideal and conceptualized representation of the GROW Citizens' Observatory (*Figure 1, Table 1).*

One of GROW's distinguishing features among other projects is its aim is to focus on 'closing the loop', moving from citizen issues

Fig. 1. GROW Citizens' Observatory model

Table 1. The framework stages of GROW Citizens' Observatory

GROW phases	Description	Activities
Scoping	Map identify issues, positioning missions, infrastructure, participants, data, services, criteria	Research citizens, experts, policy Mapping issues and concerns Platform and product development Gap analysis Citizen science Best practices for CO's
Community building	Recruitment, on-boarding citizens, experts, policymakers	Engagement and communications with kindred networks Community storytelling Themes Media partnership Community champions
Discovery	Education and building understanding, context, science, protocols, mission aims and objectives	Learning and training Data literacy Peer and social knowledge exchange
Sensing	Data gathering and observations using technology and with citizens, sharing data	Sensor distribution Deployment Data upload and access
Awareness	Data literacy, analysis, application and action	Webinar Workshops Celebration Data access, aggregation Sharing insights Scientific or expert interpretation Critical reflexion with citizens
Innovation	New datasets, prototyping and testing services with users, validating CO platform and infrastructure	Design for new services Business proposals New resources and assets for communities Robust protocols and datasets
Advocacy	Policy, soil, services, technology, robust data, CO approach	Championing Bi-laterals Change: in practices, policy, uptake External appropriation Sustainability of the project, tools and outputs Interventions

and data collection to development of critical innovative services with the value given back to citizens, experts, and policymakers. The challenge generally for COs is moving from a top-down contributory model of citizen science to a more distributed model, and to sustain community building and engagement throughout the project cycle. The GROW Model structure outlined in *Figure 1* provides a mechanism to develop and overview the whole cycle and set the direction when planning, developing, delivering and evaluating the primary steps to:

1. generate, share and utilize data and information presented and adapted to a range of stakeholders;
2. address community, science and policy challenges;
3. innovate in services using GROW data for land and soil issues of participants: citizens, decision-makers and scientists.

Results, the concept and elements of GROW

Having used the model described above, the following major elements and tools have been developed to support the public engagement process and to structure the sensor data and the important covariates provided by citizen science activities into a functional platform to store the data and make it publicly available for any further scientific or commercial use. The monitoring system has two main factors influencing the final database quality. The human factor is the depth of engagement, the level of knowledge and interest. The backend system and sensor infrastructure is the technical factor. The results are grouped and presented in these contexts.

Elements of engagement tools developed and integrated into the procedure

GROW Missions

The definition of a GROW Mission is a period of coordinated citizen science activity, that can involve observations, sampling, and sense-making, designed to deliver a clearly stated output linked to a GROW ambition. Each Mission represents a complete cycle through the seven stages of the GROW Framework. GROW Missions bring together a community of citizens and stakeholders in science and policy to collaborate on research for environmental monitoring, whose issues have impacts related to land cover and land use. Pilot Missions were delivered in the first year of the project to test project concepts and infrastructure, and two main Missions were then defined from year two of the project:

a) Changing Climate Mission

This mission is open to those located in 9 GROW Places which were selected using key criteria through an open call. We are focusing the sensors in a limited number of areas because a high density of measurements is the most valuable to science. Additionally, there is a limited supply (15,000) of the low-cost soil sensor we are using in GROW. In this mission, we are deploying several thousand soil sensors around Europe, which send soil moisture data back to the GROW Observatory. These data are used to validate soil moisture readings taken by European Space Agency satellites and to inform decisions by food growers and policymakers, ultimately the ambition is to help society adapt to extreme climate events.

b) Living Soils Mission

This mission is open to anyone, anywhere. The aim is to develop and support an active network of small-scale growers and gardeners who grow food by using and collaboratively investigating, practices that regenerate soils and create resilient ecosystems. Two key elements are the provision of scientifically robust information on selected regenerative practices such as using mulches, reducing digging or tilling, and growing polycultures via free massive open online courses (MOOCs). This was combined with a citizen experiment on polycultures called the Great GROW Experiment, which was designed to enable individual growers to investigate whether growing three crops together in a polyculture or separately in monocultures was more productive. A final element is the sharing of planting and harvesting times for key crops to improve localized growing advice available in the GROW Observatory App.

GROW Places

GROW Places (GP) are an innovation for the delivery of a CO sensor network. They contribute to the mission of delivering a viable, high-density distribution of sensors across geographically diverse areas, using geographic and scientific criteria, designed for scientific exploitation, and enabled by the participation of a place-based community. GROW Places were specified as focus areas for citizen science activity, that provide GROW with a mechanism to establish direct contact with local growing communities in Europe *(Figure 2).* They have been defined as a solution for sensing activities and to meet the geospatial requirements of the 'gridded product'. Up to 15,000 Flower Power soil sensors (Parrot Drones SAS, Paris, France) are available to participants in GROW Places. These are a formally commercially available product, a detailed description can be found in *Description and technical details of the sensors used in GROW Observatory.*

Fig. 2. GROW Places around Europe

GROW places are carefully selected areas where the capacity of engagement and the spatial and technical requirements of the soil moisture monitoring network meet. To create a representative spatial coverage of sensor deployment a clustered-nested monitoring network was designed. The GROW Place areas represent the regional heterogeneity of Europe, selected by climatic regions. Within these 50–100 km wide windows, there are the local clusters nested, which cover the topographic, microclimatic and soil heterogeneity. The degrees of freedom of the networks' coverage is limited by the available stakeholders and clustering communities, but this way of constructing the network can provide results from the beginning. The details of the selection method described in *Spatial coverage, the relation of observation network development and engagement process.*

Community Champions

Community Champions (CC) are 'ambassadors' on the ground. They support local community participants through the provision of a sensor and materials needed for the sensing survey as well as 'meet-ups' to provide support and training for participants. Through the Community Champions, GROW is able to build a network of engaged participants in each GROW Place. CCs are the regional organizing force on each GPs, they are directly and continuously connected to project partners, feedback and action are through CC organization.

Online Community

GROW's online community is central to meeting GROW's ambitions to engage thousands of people in sustainable soil management and food growing. The online community has access to training materials, information sheets and support materials. Our communication strategy brings novelty through the application of the 'Storytelling method'. Through GROW's online community and tools (discussion forum, knowledge base, learning platform, social media), users can upload and explore data, discuss findings and share stories. The aim is to promote deeper engagement – as the primary goal is for the participants to talk to, learn from and support each other, rather than receiving top-down information from the GROW team.

Experimenters' community

The Great GROW Experiment, part of the Living Soils Mission took a different approach to engage and work with the community. It delivered an innovative hypothesis-driven rather than an observation-based approach to citizen science. This was founded in training citizens in how to do research in their growing space as well as in how to implement the experiment and interpret their own results. As such, it requires the intensive investment of both time (across the growing season) and growing space for participants and is likely to attract fewer participants than simpler observation-based approaches (Bonney, R. *et al.* 2009). Experimenters were supported from May to October 2018 with regular emails, a dedicated online forum, and monthly live meetings where they could learn from the scientists running the experiment and share insights with each other. MOOC courses assisted in training citizens, culminating in helping experimenters to graph and understand their own experiments. This approach not only enhanced a sense of community and learning, but also provided valuable insights into the progress of the experiment, issues with crops, and technical limitations for data input. In later online meetings and in the final MOOC, initial results were shared and discussed, allowing participants to contextualize their own findings with those of others. We have observed this approach achieved a high level of deep engagement, for the participants. This committed small group of individuals is making clear plans for continuing experimenting on their own and involving their communities.

Online learning – GROW Massive Open Online Courses (MOOCs)

An innovative element of GROW is providing rigorous training for citizens in scientific protocols for data collection. This is seen as an approach to improve data quality and validity by enabling cohorts of citizens to receive training and grow their confidence in providing data. Data quality of measurements is a particular challenge in citizen science (Hecker, S. *et al.* 2018), especially with a large number of participants distributed over a wide area, or even an entire continent. It is widely acknowledged that the ways in which citizens learn and gain knowledge are changing, with new tools and educational materials available to foster citizens' autonomy and responsibility for change through lifelong learning. In addition to training in techniques, each MOOC also offers a recruitment opportunity. It builds a cohort of learners who become familiar with GROW's aims and activities and who can access and sign up the GROW Observatory's wider activities outside the MOOCs. Online learning is the tool of quality assurance and also important in raising interest, develop communities and cluster common knowledge.

Elements of database development

The data provided by the CO is the output and the tool for further engagement. The quality and applicability of the resulting database is the best measure of the COs functionality. In order to structure the contributions and make them accessible for any further use, the following tools and elements were developed and integrated into the framework.

Data quality assurance and data governance

1. Sensing Handbook and Sensing Manuals

The Sensing Handbook and Sensing Manuals are printed and downloadable

training resources in use by participants, translated in the local language of GROW Places, that communicate the Mission objectives and instructions for:
– identifying a suitable location for the sensor;
– placing and registering the sensor;
– carrying out the land survey;
– troubleshooting and accessing support.

2. Sensing infrastructure

The GROW Observatory aims to set-up a pilot citizen soil moisture monitoring network with 15,000 deployed sensors EU-wide from the beginning. The data, generated by the CO will be incorporated in GEOSS and used to validate for soil moisture SAR remote sensing data. The gridded product creation and Sentinel-1 soil moisture model ground-truthing were the two main aims for GROW soil moisture data. The scientific criteria and quality assurance were designed to satisfy these aims and form the basis of the soil moisture sensing aspect of the CO. The intention is to develop the platform further to connect other brands and do-it-yourself (DIY) soil sensors.

The upper 10 cm of soil dynamic properties vary fast in time and highly within a small area. Sensor measurements' inaccuracy can be dissolved in the real range of values. To be aware of the quality of the generated database the sensors were tested two ways. One is against professional, calibrated probes and the other is in the laboratory, measuring real values of water content as described below.

The Flower Power sensor logs soil moisture, soil surface temperature, light intensity, and conductivity measurements every 15 minutes. The device can store 80 days' worth of measurements which is accessed with a mobile app through low energy Bluetooth connection. The application to connect the sensor to mobile devices only runs on Android and iOS systems. Batteries will last for 6 months in summer and 4 months in the winter period, on average (depending on temperatures).

The measured values are:
– Air Temperature (Range: – 5 °C to + 55 °C; Accuracy: +/– 1.5 °C).
– Light (Range: 0.13 to 104 [mole × m^{-2} × d^{-1}]; Accuracy: +/–15%). The light sensor is calibrated to measure Photo-synthetically Active Radiation (PAR), defined as light in the wave length between 400 and 700 nm.
– Soil Moisture (Range: 0 to 50 [v/v %]; Accuracy: +/– 3%).
– Fertilizer level / Conductivity (Range: 0 to 10 [mS × cm^{-1}]; Accuracy: +/– 20%).

The soil moisture measurements are the main focus of the CO, but the other values documented give good environmental data of the current state of soil and weather. Information about the sensor location is generated the first time data are uploaded using an internet connection from the device to the Parrot cloud. This can generate inaccuracy in the geolocation entered in the database since the internet connection is needed at the sensor location. The ability to amend sensor coordinates is included in the Collaboration Hub (CH) but requires a European wide campaign to train and motivate users to use it.

3. Quality check of sensing infrastructure

FP sensor performance compared to professional probes.

In order to evaluate the performance of the Flower Power soil moisture sensors, they were placed alongside professional probes in two different study areas, located in Austria and Italy. The main study area is the Hydrological Open Air Laboratory (HOAL, http://hoal.hydrology.at; Blöschl, G. *et al.* 2016) located in Petzenkirchen, Austria. HOAL is an agricultural catchment covering 66 ha and equipped with soil moisture stations (20 permanents and 11 temporaries). The permanent stations are located in pasture and forest, while the temporary stations are installed in agricultural fields and are removed on a regular basis to allow for field management. The majority of the stations are equipped with SPADE Time Domain Transmission sensors, one station uses the Decagon 5TM sensor to measure soil moisture. The sensors are installed in a horizontal position at different depths: 0.05 m, 0.10 m, 0.20 m, 0.50 m and 1.00 m. In addition, there are two professional soil moisture stations installed 20 km North of Petzenkirchen, in Dietsam, Austria. They are located in grassland and equipped with Decagon 5TM sensors in a depth of 0.05 m and 0.10 m.

A total of 37 Flower Power soil moisture sensors were placed on the 30th of April 2017 alongside the technical grade sensors in the HOAL catchment, four on the 24th of May 2017 in Dietsam. Up to the beginning of 2018, 7 additional sensors were placed in Petzenkirchen and 3 sensors had to be replaced in Dietsam. In total, 51 Flower Power sensors were used to evaluate their performance in comparison to 31 professional probes in Austrian test sites. The Flower Power sensors are installed vertically, providing information about the water content of the first ten centimetres of soil. The comparison period between professional and Flower Power sensors ranges from 2 to 10 months (due to different installation dates and/or removal caused by field management practices).

The second study area consists of two sites located in Umbria, Italy. The first site 'Petrelle' is part of the network 'UMBRIA' (Brocca, L. *et al.* 2011), which is part of the International Soil Moisture Network (ISMN, http://ismn.geo.tuwien.ac.at/; Dorigo, W.A. *et al.* 2011a, b 2013). The 'UMBRIA' station is equipped with ThetaProbe ML2X sensors, installed vertically (0.05–0.15 m and 0.15–0.25 m). The second site consists of two professional stations of the network 'HYDROL-NET_PERUGIA' (Morbidelli, R. *et al.* 2014), which is part of the ISMN as well. At these professional stations, TDR TRASE sensors are horizontally installed at a depth of 0.05 m. 2 Flower Power sensors were installed next to one professional probe from the 'UMBRIA' network and 4 Flower Power sensors were installed alongside two professional stations of the network 'HYDROL-NET_PERUGIA'. The Flower Power sensors were installed in the middle of November 2017 and provided data for more than two months.

As shown in *Figure 3* good agreement of the temporal variability between the Flower Power and the professional soil moisture sensors can be observed in both study areas. For the sensors located in Austria, a stronger response of the Flower Power sensors to precipitation events is visible which can be explained by the different sensor positioning. A more or less pronounced bias between the soil moisture levels from the low-cost and the professional probes can often be observed, and is not surprising due to the lack of site-specific calibration of the Flower Power sensors.

However, for satellite validation, the soil moisture relative variability is of higher importance than the absolute values. Therefore, the scientific goals of GROW remain inviolate, but accurate measures of absolute water content in the soil would be more valuable for farmers and growers.

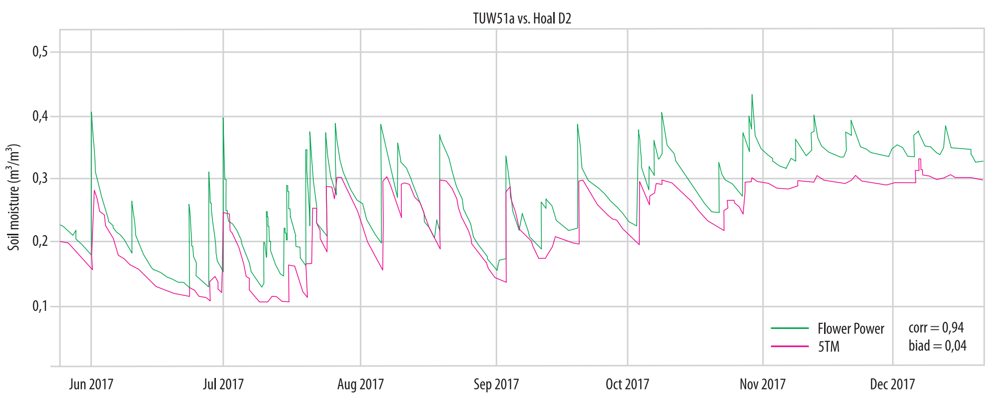

Fig. 3. Time series plots of Flower Power and 5TM (0.10 m depth) soil moisture readings in Dietsam, Austria

4. Laboratory testing of Flower Power sensors

Flower Power sensors were validated in laboratory conditions in four different kinds of soils and two different setups; 28 sensors were deployed on four different kinds of soils (seven sensors for each: clay loam; sandy loam; loam; loamy sand). Two different experimental setups with four sensors were installed into the same container for cross-validation and three sensors were installed in separate containers with large diameters to test the measured soil volume and for cross-correlation.

First, four different types of natural soils were selected and prepared and laboratory tested for basic chemical and physical properties. The volume of the samples was measured and recorded and then the soil was saturated with water and the weight of saturated soil recorded. The saturated soil samples were dried naturally for 31 days in an undisturbed room and the weight was measured each day with exact time records. The actual soil moisture content was calculated for each measurement and the measured values were compared with the downloaded Flower Power sensor data for the same time. Statistical analysis to define the measurement uncertainties and its soil type dependencies were performed. Conclusions were that there is a clear correlation in the levels of uncertainty identified. Flower Power sensor measurements on dryer soils have larger positive divergence from the actual measured value, of around 40 per cent moisture content and overestimated moisture when below 40 per cent actual value, and underestimated it above 40 per cent actual soil moisture. The cross-validation among the sensors was more or less constant, except in very dry conditions due to the cracking of the soil. Flower Power measurements had a severe distortion in dry soil moisture conditions (< 20%) and can almost double the real value.

In the most common soil moisture range (20% to 40%), the estimation differences are less than 20–25 per cent. Within the sensors, variation does exist but is negligible, but cross sensor variation can reach 15 per cent. The deviation from the lab measured values show a very strong trend line – the deviation increases towards the dry section. There are significant differences between the different soil types, but the same trends can be observed in Flower Power sensor measurement uncertainty *(Figure 4).*

The sensors performance measuring the real water content was not so reliable, but sensitive enough to detect spatial variability of soil moisture. Measurements for direct

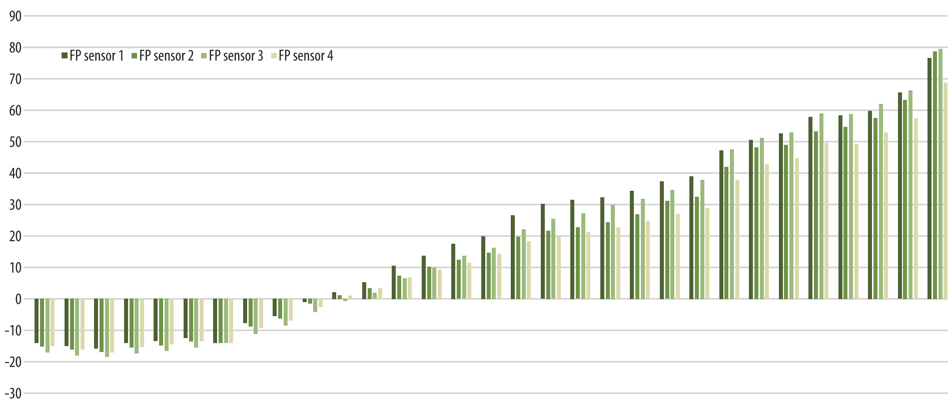

Fig. 4. Deviation from the laboratory measured soil moisture, based on four repetitions of FP sensor measurements for all conditions

agricultural decision making are not sufficiently accurate, but by empirically the sensor user can get information as within sensor variation is negligible. The purpose of creating continuous soil moisture maps by extrapolation gives some difficulties but to represent spatial variability of soil conditions the sensors are suitable. Other parameters measured by Flower Power sensors were not validated as soil moisture is the primary dataset to be used for the project aims.

5. GROW Observatory mobile app

The GROW App provides three services to growers: it provides a local growing, planting and harvesting advice for small scale growers, gives practical information on specific growing approaches that will also improve soils and ecosystems, and it allows the submission of site description for the Changing Climate mission. Information on suitable crops is derived from GROW's Edible Plant Database and is interrogated based on the phone's GPS to show crops that are suitable for the location and time of the query. Each crop has detailed information on site requirements and cultivation. The practice-based information highlights the value of specific regenerative practices as well as guidance on how to implement them. The site information data gives step-by-step guidance for a consistent land-survey for the placement of each sensor including the categorization of side position, slope, canopy cover, and aspect-oriented site photos to enable a consistent comparison of sites.

6. Data platform development

The data collected in GROW is made available to growers and other interested stakeholders through the GROW data platform (*Figure 5*). The two GROW front-end services, the Collaboration Hub and the GROW Observatory mobile app, are both connected to the GROW user account database. This ensures that participants can use their GROW user account for both services and data collected by the user through different channels can be combined. Data from the Flower Power sensors is collected in the field using the Flower Power mobile application. After a Flower Power account has been created in the mobile application, it connects to the sensor via Bluetooth and uploads the data to the Flower Power database.

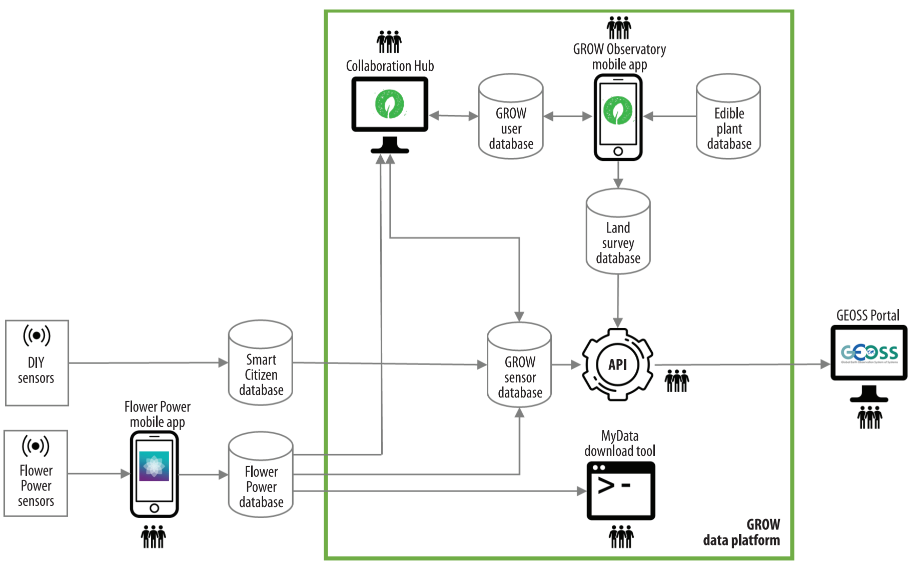

Fig. 5. The GROW data platform (in the green box) and connected external applications and tools

Growers register their sensor with GROW through their user account in the Collaboration Hub. After successful registration, the GROW sensor database starts to request and store all sensor data collected by the user from the Flower Power database. The Collaboration Hub requests these data from the GROW sensor database and displays them in the user's personal pages. The visualization includes line graphs of the sensor observations and a map with the sensor location. If the location is not correctly registered, users can adjust their sensor location in the Collaboration Hub and the corrected location is saved in the GROW sensor database.

The GROW Observatory mobile app requests information about suitable plants for the user's location and time of year from the Edible Plant Database. Data collected in the mobile app by users performing the land survey is stored in the Land Survey database.

Scientists and companies interested in working with the data collected in GROW can access all data or a selection based on geographic extent or time span through the GROW API. These data are also discoverable through the GEOSS Portal (http://www.geoportal.org/), where Earth Observation data from archives all over the world can be searched.

Individual users who would like to access the sensor data they collected, can use the MyData download tool. This is a simple program that asks the user to provide the username and password of their Flower Power account, after which it requests all data for this user from the Flower Power database. For each sensor that the user owns, the program creates a text file with the data.

7. GROW Data Governance and Infrastructure

Standards and infrastructure are central to GROW – or, indeed, to any CO – and need to be developed and maintained beyond the life of an individual project. GROW is underpinned by standards and infrastructure that are detailed below. The values of GROW relating to handling and sharing data are set out in the GROW Data Governance statement. These, in turn, reflect the core values of the project.

8. Service Innovation

Through innovation, GROW aims to deliver services based on collaborative data to enhance the GROW experience for its stakeholders and create an interface with specialist data users in science, policy, and business. Through a human-centred design approach, the needs and interests of users and specialist audiences in science, industry, and policy were scoped in the early stages of the project. This user research underpins service design and development to achieve an effective transfer of environmental knowledge to policy and other specialist communities and the widespread uptake of GROW data and information.

9. Observatory Policy Interface (OPI)

One of GROW's aims is to promote and enable more effective and inclusive participatory governance around the management of soils. Soil-related problems are complex, uncertain, multi-scale and impacts upon multiple actors and stakeholders. The OPI helps to inform the underlying assumptions and resulting assertions to establish how participants can inform policy through data gathering and active engagement. This is supported by leveraging established relationships with the policy community to communicate findings to policymakers and forums.

10. Data dissemination and visualization

The Collaboration Hub (CH) is a place to be part of the GROW community and to connect and discuss with other stakeholders. It is where people connect their soil sensors to the GROW database and where participants can visualize and compare their observations to regional and local environmental data.

Data visualization and interpretation is one of the project's most important tool of engagement, education and raising interest. Most participants operating sensors are generally aware of the soil conditions of their property and can manage this instinctively by experience. But the recorded dataset, which documents the changes and anomalies throughout time, offers a higher level of knowledge. The CH is the platform where the recorded and interpreted soil moisture data and the participants' knowledge and experience are joined together. Local groups can discuss and analyse the measured values, participants of different professional levels interpret their soil conditions.

11. Interpretation of measured soil moisture

Different levels of data visualization have been developed within the GROW Project. The first encounter with the measured soil moisture data occurs when a user connects the sensor with the smartphone to download the logged measurements. The Flower Power smartphone application connects to the sensor, downloads the data and then uploads to the service provider's data storage cloud. On the server side, averaging is made to make the dataset scalable then the processed dataset is downloaded to the device, where a scalable graph view visualizes the measured values. The app contains a global plant database of 7,000 species and varieties and the graph view compares the actual values to the plants' water, light and temperature needs.

Further data visualizations are planned for GROW's CH so participants can compare their observations to regional and local environmental data. One visualization will display long-term average characteristics of the water balance in the plant-soil-atmosphere system at the site of the sensor. Long-term monthly mean values of potential evapotranspiration, actual evapotranspiration, rainfall, and mean daily temperature which together defines periods in the year with specific soil hydrologic situations such as water surplus, water utilization, water deficit, and water recharge having a potential impact on cultivated plants/agroecosystems. Other ecological interpretations of the measured soil moisture will display the temporal record of actual soil moisture in the top-most soil layer (0–10 cm) as measured with soil moisture sensor (volumetric %) at the site/parcel with soil moisture measurements. There are plans to display background static values of soil moisture ecological intervals (re-calculated into volumetric %) estimated for the soil texture class taken from the underlying soil map/grid based on GPS coordinates of the sensor.

12. GROW gridded product visualization

Gridded products generated from point measurements and user's land and soil observations are the visual interpretation of the collected data and the continuous extension of point measurements for the entire area of the GROW Places. The quality of the estimation for the area between measuring points depends on the distribution of the sensors and the quality of the explanatory variables (other sources of environmental data available for the relevant area). A methodology for the extrapolation of measured soil moisture data for the area of Europe will be developed, using available free source environmental data as explanatory variables. Also, measurements of the error of the estimation of values for the intervals between measuring sites will be elaborated. This will facilitate the use of GROW data in climate modelling, drought/flooding forecast or in precision agriculture. In the Miskolc area (NE Hungary) a pilot area was established for which high-resolution environmental data (relief, land cover, soil, and daily meteorological data) are available. A dense network of soil moisture sensors had been set up and two months of soil moisture measurements collected. The resulting dataset was used to create a time series of a gridded product with varied density of sensor network and with different explanatory variables, for known weather events. The gridded product pilot aimed to set up the optimal distribution pattern for sensor measurements for the GROW places. This is part of the sensor distribution plan synchronized with the demands of citizen engagement. As a result of the gridded product pilot, a set of environmental variables was listed which are needed for gridded product development for GROW place areas. This visualization will be used in the engagement process.

The point soil moisture measurements gathered by the observatory are processed, analysed and interpreted. The most powerful tool for visualization is the continuous prediction map of soil moisture for the available biggest areas where the sensor spatial distribution allows. The sensor distribution plan was developed to generate a spatially coherent, and representative sensing network. The aim is to interpolate the point information and estimate the properties for any non-visited site, create a continuous surface from the point observations. These soil moisture layers represent the final products of the monitoring system. The performance or accuracy of the estimations are functions of the spatial coverage of the point measurements and the availability of accurate, high-resolution explanatory variables. Open source environmental data is used for the soil moisture map development.

As the sensor deployment moves forward during the project, the soil moisture maps will have higher accuracy and greater spatial and temporal coverage, providing richer data over larger geographical areas and engaging more stakeholders. Some GROW participants are professional agro-producers, and this stakeholder group is interested in the spatial and temporal variability of the soil within their property. To satisfy this demand a sophisticated, artistic visualization of the data is to be provided in addition to scientifically accurate soil moisture maps.

13. Visualization of experiment data

The original intention was that experiment participant would be able to see their own data graphically as they submitted it. However, this proved beyond capacity within the timescales of the project. Instead, visualizations were produced by scientists during the experiment to show collective results at various stages. Thus, participants could understand that the data they submitted was of importance, and see how their own experience compared with the collective results. Productivity data were represented in simple graphs showing that polycultures tended to be more productive. In addition, animated graphics (in .gif format) were used to show maps of monthly productivity from each site for the monocultures and for the polyculture and presented side by side to allow both participants and other interested parties to watch the monthly yield data change. Here participants could see how their site compared and also see patterns e.g. earlier harvests in the South of Europe and later harvests coming in in the North. A full report of the experiment will be described both in the scientific literature and as a public-facing accessible summary. It will be used to guide advice for growing from advocacy organizations like the Permaculture Association (Britain).

Provisional results of the GROW system establishment

1. Spatial coverage, the relation of observation network development and engagement process

A monitoring network like the GROW Observatory will have spatial biases as it relies on citizen scientists. Thus, the requirements of spatial and temporal coverage of the network need to be carefully designed with recruitment and engagement protocols. The scientific objectives within GROW, like creating a gridded soil moisture product based on citizen's observations using low cost soil moisture sensors and freely available environmental explanatory variables; and to provide an extensive dataset of *in situ* soil moisture observations which can serve as a reference to validate satellite-based soil moisture products and support the Copernicus *in situ* component set up restrictions on the areas to be sampled and strong demands on participants. The sensors must be deployed in as many different climate regimes, land cover classes, soil types and topographic positions as possible, on representative, non-urban areas and the longest time span of continuous observations are crucial providing data for climate-related applications, validation of satellite-based products and Copernicus.

Therefore, the main static scientific criteria were the followings:

- meaningful geographic coverage (climate, soil, land use, agro-technology) size approx. 50 × 50 km, can be described by approximately 1,000 sensors;
- soil, terrain and land use variability, with relatively large homogenous units;
- good quality environmental data (terrain, soil, and land use);

– having a scientific institution capable of supervising the process;
– interested local organization to maintain and extend the network for later network expansion-community champion approach, demonstration CO network development to test the engagement, awareness raising strategies and toolsets.

However, the GROW project was initiated to demonstrate the development of soil moisture monitoring CO network. The first invitation round resulted in several scientifically appropriate areas, a good pool to choose the Grow areas. Thus, the first priority area list has been refined based on the need to have a strong and reliable partnership between a GROW partner and the local community champion. A strong relationship of the local community with the GROW consortia also can support good quality local environmental data (terrain, soil, land use) availability.

To achieve the best selection, a clustered-nested sampling strategy was developed to cover most of the geographical diversity for the area of Europe. In parallel with the exploration of potential communities, GROW Places had been designated based on the Köppen-Geiger climate classification to cover the most of climatic homogeneity within the area of Europe. GROW Places are geographic focus areas where a high quantity of Flower Power sensors is deployed to record soil moisture and associated data at a high density of observations. They are in specific areas in Europe with strong stakeholder buy-in. The originally selected 17 priority areas covered 4 dominant climate classes: Cold, without dry season, warm summer; Temperate, without dry season, warm summer; Temperate, dry summer, hot summer; Temperate, without dry season, hot summer.

Sentinel-1 ground truthing for soil moisture modelling requires further restrictions of the sensor placement. The reliability of remotely sensed soil moisture products is influenced by the presence of water bodies and rough topography. Thus, GROW places with a smooth topographical surrounding and a low percentage of water bodies are favoured. For each GROW places ancillary dataset were used to derive topographic complexity and wetland fraction at the scale of a satellite footprint (Dorigo, W.A. *et al.* 2015), but this selection was used only as a starting point to contact local communities and start concrete discussions about the implementation of the GROW places. From that contact round, it became clear that some of the selected GROW places had to be updated and others replaced as no supporting communities could be identified. An enthusiastic community champion is a key to the success of continuous data collection. The scientific criteria were not used to select GROW places but were used to evaluate them, especially new GROW places. When adding new GROW places, only the climatic zone criteria were used to evaluate the relevance of the geographic location of the proposed locations. The engagement process outputs were placed as the first priority, and provided with a set of real GROW places, with committed local actors. A wide range of the European climate regions, land use types and topography are covered by the eight final GROW places: Evros and Laconia (Greece), Southeast and Northwest Ireland, Miskolc (Hungary), Barcelona (Spain), Algarve / Alentejo (Portugal), Tayside and Central Belt (Scotland), Vienna (Austria), ’s-Hertogenbosch (Netherlands), and Luxembourg.

Within the regional level, there are the nested dense observation clusters representing the local diversity of soil, land use, and topography. This usually covers 40 to 1,500 hectares with high sensor density. Here stakeholders are communities of sustainable growing practices or agricultural producers with economic interest or research institutions. These dense sampling networks are complemented by observation points in between covered by smaller-scale growers with few sensors deployed.

The primary demographic of GROW is small-scale growers, professionals, and hobbyists, who were expected to be financially independent, intellectually curious and emotionally connected to growing. One strong motivation for joining a growing community is found in the common need of living in a sustainable and harmonious environment close to and minimize harm to nature. The overall communication and engagement strategy and toolset were developed to reach out to this type of audience.

2. Piloting engagement and sensing network development

To test engagement tools and procedure within the constraints of the scientific criteria three pilot missions were set up on GROW places: Alexandroupolis (Greece), Cloughjordan (Ireland) and Miskolc (Hungary), where project partners were involved. The main objectives of the pilot missions were:

– to validate scientific usefulness of the data through satellite validation activities and preliminary gridded products production;
– to validate the material, protocols, and instructions for citizens to deploy, and to maintain the sensing network from a scientific point of view;
– testing local aspects of the engagement protocol (participant pathway, community champions) for engaging participants within the project;
– validating that the growers are able to take benefits of the sensors and additional activities, and to test GROW's back end system and its capacity to collect and provide the data to users. The missions were implemented by project partners from participant recruitment through workshops and training and sensor deployment.

One very important point to note about the pilots is even with well-developed engagement tools, it can be difficult to implement on a local scale. GROW Places are large areas throughout Europe, where social, demographic and economic differences result in the different target audience and require different ways of communicating and training. The overall strategy and tools can result in different levels of engagement and generated data quality depending on location. Global tools are for highlighting the aims and objectives but the local organizing force is indispensable.

With small-scale growers, the emotional connection to their work is strong and engagement is possible through workshops and awareness raising. This demographic is motivated to observe their soil and environment, but the number of sensors available for them to deploy is very limited, therefore, spatial coverage is random and dispersed if there is no community for a local clustering role. Thus, the database resulting from these observations is not suitable for growing consultancy, nor for validating that the growers are able to take benefits of the sensors.

Technical difficulties influence the extent and speed of engagement. GROW aims to deploy 15,000 relatively low-cost commercial soil moisture sensors. The commercial product contains all backend services of data download, storage, and query which is provided for all participants of the project. Sensor usage training is limited to the operation of the plug-and-play product. Even with these limits in place, during the pilot missions continuous technical support was needed for sensor deployment, data upload and data connection to CH. Small scale growers, using a small number of sensors, may face problems with the technical infrastructure and on occasion need personal assistance. It is not feasible to address these issues and to support participants on an individual basis, although emerging problems are unique.

One important issue noted within this project, the extent of which is heterogeneous throughout Europe, is the physical security of properties. The North East Hungarian pilot faced serious problems of sensor disappearance by theft. This is a very limiting factor of spatial and temporal coverage. As an example of specific land use, in vineyards where harvesting is carried out by contracted seasonal workers be monitored during harvest time, sensors must be removed for the period of one to months. Unfortunately, when the sensors are not deployed over the late summer and early autumn, it is not possible to provide important data on the phenological state of the grapevines in preparation for the winter. Soil moisture over this time period is important for the vines' nutrient uptake, and, thus, heavily influences the force of sprouting in springtime. So, important data with forecasting potential is lost as a consequence of having to remove the sensors during harvesting.

As the project aims to set up a long-term, self-sustained CO during the funding period, the time-frame of engagement and sensor deployment is limited. With sufficient professional and economic interest from agricultural producers and scientific researchers, sensor deployment could be accelerated to ensure high quality, reliable and continuous observations. Communication towards these potential stakeholders was only undertaken by project partners, with no general communication and engagement strategy developed.

GROW's science partner responsible for the gridded product development and data quality (University of Miskolc), set up a pilot mission with two professional stakeholder companies, with whom previous research collaboration had been established prior to GROW. The pilot areas cover two different land uses: vineyard and arable land. High sensor density provides data from representative sites of soil and topography. To set up the monitoring network, the science partner deployed the sensors based on high resolution local environmental data and empirical knowledge. Regular readings are implemented by researchers with the help of the stakeholders, and harmonization of the data needs of producer and research is being undertaken. Continuous effort is made to generate an up-to-date operative database for professional agricultural decision-making and research purposes.

One important issue is the frequency with which the sensor data is uploaded into the database. Retrospective access to the database can still be of use for scientific research, but agricultural consultancy requires a regularly updated database. The fundamentals of an operational up-to-date monitoring system that can provide data for agricultural consultancy and forecasting, must be set up with scientific vigour and needs an extensive infrastructure of sensors and data storage and processing and a technical front end application to serve decision making.

Conclusions, achievements and challenges identified

One of the important roles of the GROW project has been to set up standards and protocols for soil moisture monitoring carried out by citizen observation networks, to meet scientific and professional criteria. Science protocols are set, harmonization with professional agricultural needs is being implemented in the second half of the project. Science can provide data quality assurance and reliable data interpretation, but a functioning CO gives the platform to science to create data interpretation useful for citizens. However, along with the advantages and potentials of the CO approach, several challenges have been identified as well.

One of the most important findings is that the results of 100 years of public awareness raising and tradition, like the bird watching example or the weather watchers, is difficult to replicate within a few years. Huge efforts are needed for topics like soil moisture to be integrated into common societal knowledge. Awareness raising and public engagement strategy development are the two most critical elements of any success, where top-down efforts supported by policy-making can make a difference.

Data representativity is also a relevant issue. A good monitoring system needs to cover all different kinds of environmental settings, defined by geomorphological, land use and soil properties – among others. A system targeting small-holders may result in a spatially biased, incomplete distribution of the monitoring sites, where the point density is high within the village and low or even zero for areas outside of the villages. The soils of the small-holders garden are often changed by cultivation, artificial additives, therefore, the point may represent only a small neighbourhood, extrapolation of its information is often limited.

One potential means to accelerate the development of a high-quality soil moisture monitoring system in Europe is to move towards engaging with large-scale agriculture, which would require an increasing interest in maintaining soil moisture monitoring systems provide public data. Such a reliable data source could catalyse break-through in all the disciplines affected in earth observation, climate modelling and precision soil and land management and use. The GROW project as a top-down initiative funded by the European Commission has the potential to initiate these necessary processes. With the tools of engagement, communication, training and awareness raising enforces the bottom-up development of the CO, reaching out to the widest spectra of interested stakeholders. This catalyses self-organizing data communities with the interest in soil monitoring, which through open source APIs and DIY sensors can develop sensing and data infrastructure, or economic interest sets up professional networks with researchers. Based on the pilot missions' experiences GROW involved larger scale agriculture and research institutions in the targeted audience. DIY sensor knowledge base and an API to connect any soil sensors to the GROW Collaboration Hub had been developed and will be communicated to the end of the project.

A major finding of the GROW project is that low-cost soil moisture sensors can provide data both for home and for scientific use. However, some conflicts between the home user and the scientific interest have been identified. Sentinel-1 data is sensitive to soil moisture of the upper 10 centimetres. This layer dries out and can be rewetted fast. The layer directly below the soil surface represents a more stable source of available water for the plants. Therefore, sensors deployed under the surface layer would provide more relevant information for the grower, but less representative for the Sentinel-1 data validation and calibration.

It has been concluded, that these low-cost sensors have a relatively good performance. The comparison of several readings from the different sensors within the same condition was quite consistent. However, a significant deviation from the lab measurements was identified, probably due to the built-in soil moisture estimation algorithm. It is known, that different soils have different relationships between their dielectric constants and their soil moisture content, so different estimation algorithms need to be fitted to different soils. Any common platform aiming to integrate different sources of data should take the direct raw measurement and apply the appropriate algorithm afterward to avoid inconsistency due to the different estimation algorithms applied within the different kinds of sensors.

The ground truthing of the Sentinel-1 soil moisture model's main criteria is the availability of fresh, up to date data. In order to develop a close to real-time, operational data platform providing up to date soil moisture estimations need to have more frequent data upload to the server. The strong interest of data providers to ensure frequent data upload is the issue to emphasize. Besides of the traditional engagement mechanisms described in this paper, other innovative approaches for better outreach to the society, like the integration of environmental art to catch broader community attention is also initiated and currently being developed.

A well-functioning back end system of sensing, data storage and visualization can provide a stable environment for database continuity. A good visualization of data is an important tool for science to develop data interpretation based on professional agricultural needs.

GROW must emphasize awareness-raising, communication, and engagement for the widest range of audience. The post-funding sustainability of the CO depends on the sustaining of both the communities and the infrastructure of sensing, data logging, and processing and interpretation. An engagement tool for stakeholders interested in the technical part of soil-sensing is being developed and communicated in the second part of the project. This must be emphasized because DIY sensors and open source communities can provide self-organizing infrastructure for soil moisture monitoring. An existing infrastructure of observations is more likely to generate data interpretation and visualization which is attractive and engaging for a wide audience and encourage participation.

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National level assessment of soil salinization and structural degradation risks under irrigation

Zsófia BAKACSI[1], Tibor TÓTH[1], András MAKÓ[1,2], Gyöngyi BARNA[1], Annamária LABORCZI[1], József SZABÓ[1], Gábor SZATMÁRI[1] and László PÁSZTOR[1]

Abstract

Optimal water supply of plants is key to high yields. However, irrigation in drier regions must be accompanied by soil conservation. Nationwide planning of irrigation needs spatially exhaustive, functional soil maps, which may support proper recommendations for the different areas. For supporting the Hungarian national irrigation strategy, a series of countrywide functional soil maps was created, which reveal the pedological constraints, conditions and circumstances of irrigation by the spatial modelling of the relevant functional features of the soil mantle. Irrigation can improve productivity, while its negative effects may lead to soil degradation. This paper focuses on threats, the spatial identification of potentially affected areas. The thematic maps spatially model the irrigability and vulnerability of soils. Estimation of salt accumulation hazard, and soil structure degradation risks were targeted. The salinization hazard assessment was carried out by two ways. We applied the steady state concept of critical water-table depth and a more dynamic, process-based method. To estimate soil structural degradation hazard, class-based relationships were developed based on soil profile data of MARTHA 1.0 (Hungarian Detailed Soil Hydraulic Database). Soil type, organic matter content, carbonate content, soil reaction and texture class (USDA) were taken into consideration to develop pedotransfer functions for modelling the correlations between primary soil properties and threats indicators. The new maps can help decision makers to improve land use management, and sustainable agronomy.

Keywords: functional soil map, irrigation, salt accumulation, soil structural degradation, Hungary

Introduction

Irrigation is one of the most important agri-environmental operations, which can contribute to improved productivity (EEA, 2017a). Based on the Eurostat report in 2019 the extent and ratio of irrigable and actually irrigated area were almost the same in 2003 and 2013 in Hungary. The total irrigable area in 2013 was 259,000 hectares, while the area of the irrigated lands (at least once a year) is less than 142,000 hectares, which means 54 per cent utilization. This ratio in more arid, European countries is higher, e.g. 70 per cent in Italy and 76 per cent in Greece. In some countries (e.g. Spain, Portugal, Greece, Italy), due to limited natural water resources, treated wastewater can be an alternative source for irrigation which increases both of the risk of secondary salinization (Daliakopoulos, I.N. *et al.* 2016; Elgallal, M. *et al.* 2016; Francés, G.E. *et al.* 2017) and structural degradation (Leuther, F. *et al.* 2019).

Due to climate change, water requirements for irrigation could increase by 17–27 per cent depending on crops (Esteve, P. *et al.* 2015). As a long-term forecast, the European-scale soil moisture modelling for 2021–2050 projects wetter conditions in northern, but drier ones in southern European regions, to which the territory of Hungary belongs (EEA, 2017b).

[1] Institute for Soil Sciences and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences. Herman Ottó út 15. H-1022 Budapest. Corresponding author's e-mail: laborczi@rissac.hu

[2] Department of Soil Science and Environmental Informatics, Georgikon Faculty, University of Pannonia. Deák Ferenc u. 16. H-8360 Keszthely.

The national statistics for the last ten years show that the acreage of irrigated areas does not exceed 3 per cent of arable lands in Hungary. The question of irrigation is becoming increasingly important for preventing soil dryness due to eventual extreme drought events. Sustaining proper soil moisture content is essential in agronomy. However, irrigation cannot be sustainable without taking care of soil conservation. According to the report of the Research Institute of Agricultural Economics) (Kemény, G. *et al.* 2018), about 800,000 hectares would be suitable for irrigation, but at present only ca 300,000 hectares have irrigation facilities.

An ongoing research aims to estimate the productivity growth due to irrigation by considering the agricultural potential of soils, where the anthropogenic management factors, which have an effect on the efficiency of production, are integrated into the form of scenarios, based on a new land evaluation system (Tóth, G. 2011; Tóth, G. *et al.* 2014). According to preliminary results, nearly two-thirds of Hungary's cropland would show significant increase in productivity as a result of irrigation, but in areas with poor productivity there is no significant increase in productivity with irrigation alone.

From the point of view of irrigation, its surplus (not absorbed by crops) water is an infiltrating supply, which contains various amounts of dissolved salts. Following the plant water uptake (transpiration) and surface evaporation, which consume the water of stored moisture, the dissolved salt of the irrigation water remains and accumulate in soil over time.

In irrigated conditions plant water uptake is equal to transpiration by definition when disregarding the water content of plants. Part of irrigation water is percolating down in the soil for several reasons, e.g. if water is available, irrigation is planned to be more than what is just necessary in saline areas, in order to make sure the present salt is leached down. Furthermore, the water distribution is not perfect and there is leaking from the canals; the vegetation cover is not perfect and in non-covered patches water is percolating without being used by plants (Szabolcs, I. *et al.* 1968, 1969a; Várallyay, Gy. 1989). Last but not least, in sub-humid conditions, as in Hungary, unplanned rainwater is added to the water and contributes to water table rise.

Irrigation may also have an effect on soil structure, hydraulic properties, nutrient flow (better water supply, more vigorous soil life), and regular irrigation may affect the depth of groundwater level and change the direction of soil formation as soil hydromorphisation, secondary salinization (Kovda, V.A. *et al.* 1973; Várallyay, Gy. 1989; Murray, R.S. and Grant, C.D. 2007). Sun, H. *et al.* (2018) examined the impacts of long-term irrigation on selected soil properties, and they found that irrigation timing affects bulk density and saturated hydraulic conductivity; while organic matter and total nitrogen decreased during their 17-year long survey. Irrigation enhanced clay dispersion in Vertisols of Northern Cameroon (Basga, S.D. *et al.* 2018). Tisdall, J.M. and Hodgson, A.S. (1990) found, also in irrigated Vertisol, low air-porosity, which could decimate soil faunal populations. Dong, L. *et al.* (2018) reported sand content decrease, and soil texture became finer under irrigation. In Europe, continental scale irrigation maps were generalized/created to estimate the irrigation water requirements (Wriedt, G. *et al.* 2008). Based on simulation performed by Riedeger, J. *et al.* (2014), the irrigation demands will increase in the future if the temperature rise. With satellite data, namely satellite soil moisture products, irrigation doses can be quantified (Brocca, L. *et al.* 2018).

Our objective was to present a nationwide map series of the most important risks of irrigation, e.g. salinization and structural degradation, in order to delineate the areas where special attention must be paid to the practice so that it remains sustainable.

Methods

Data sources used in the evaluation processes

– Hungarian Soil Information and Monitoring System (SIMS, 1995) is a nationwide soil monitoring programme, which provides soil information from 1,235 locations. Due to the standardized methodology and the accredited laboratory measurements, SIMS is the most unified and thematically detailed, up-to-date soil-related database in Hungary.

- Groundwater Depth and Quality Monitoring Network Data of General Directorate of Water Management (OVF) contain, among others, specific electrical conductivity of water (μS/cm), measured 1–4 times per year at 8,095 sites.
- Digital Kreybig Soil Information System (DKSIS – Pásztor, L. *et al*. 2010, 2012) is the most detailed spatial dataset related to soils covering the whole country. It simultaneously contains two types of geometric datasets: soil mapping units (SMUs) and sampling plots. In the present paper, we applied plots with pH and salt content data, as well as SMU layer with physical and chemical soil property categories. Physical soil categories were attributed according to water retention capability, permeability and infiltration rate; chemical categories were derived from pH and calcium carbonate content of soils.
- Hungarian Detailed Soil Hydraulic Database (MARTHA 1.0 – Makó, A. *et al.* 2010) was developed to collect information on measured soil hydraulic and physical characteristics in Hungary. Recently, this has become the largest and most detailed national hydrophysical database. However, it was not elaborated for mapping purpose, the countrywide sampling was not representative, neither systematic nor random, its data originate from experts' data collections.
- Digital, Optimized, Soil Related Maps and Information in Hungary (DOSoReMI.hu) database collects novel soil property- and soil type maps as well as functional soil maps, compiled by up-to-date digital soil mapping methods. In the present paper, we applied clay, silt, sand and calcium carbonate content maps.
- Climate was represented by average annual precipitation, average annual temperature, annual evaporation and average annual evapotranspiration layers compiled by the Hungarian Meteorological Service with 0.5′ resolution (Szentimrey, T. and Bihari, Z. 2007). We calculated Aridity Index, which is ratio of annual precipitation to annual potential evapotranspiration.
- CORINE Land Cover Database (CLC50 – Büttner, G. *et al.* 2004) is a national land cover database elaborated on the basis of the CORINE nomenclature of the European Environment Agency (EEA), and adapted to fit the characteristics of Hungary.
- MODIS satellite images were involved in the mapping process. Red, near-infrared (NIR) bands from two dates (16.03.2012 and 07.09.2013) as well as NDVI images providing information from 16 day periods of two dates (03.2012 and 09.2013) represented different phases and states of vegetation. Spatial resolution of the images is 250 m (NASA LP DAAC, 2015).
- Digital Elevation Model (EU-DEM 2015) and its morphometric derivatives were applied as environmental auxiliary layers. Channel Network Base Level, Elevation, Multiresolution Index of Ridge Top Flatness – MRRTF, Multiresolution Index of Valley Bottom Flatness – MRVBF, SAGA Wetness Index, and Vertical Distance to Channel Network were used in the mapping process. The terrain features were calculated from the DEM in SAGA GIS (Conrad, O. *et al.* 2015) environment.
- Lithology was represented by the Geological Map of Hungary 1:100,000 (Gyalog, L. and Síkhegyi, F. 2005). The units of the map were correlated with the nomenclature of parent material defined in the FAO Guidelines for soil description (Bakacsi, Zs. *et al.* 2014).

Mapping potential irrigation possibilities based on the critical groundwater level concept

The assessment approach targeted to evaluate the possibility of irrigation based on the steady state concept of critical water table depth, further developing the ideas used for the irrigation planning of the 1960s in the region of river

Tisza (Szabolcs, I. *et al.* 1968, 1969a, b) and extending the principles to national scale producing the „Map of irrigation possibilities". Critical water-table level is a groundwater depth value, which is based on theoretical calculations and practical experiences (Polynov, E. 1930; Szabolcs, I. *et al.* 1968). Over this level the rise of a particular saline groundwater may result in harmful salt accumulation (secondary salinization) of the root zone, where most damage is caused. As a consequence, the higher the salt content of the groundwater and the clay percent of given profile, the deeper is the critical water-table level. Examining a particular case, the critical water-table level is affected by the stratification of the soil layer, but not at national scale. *Figure 1.* shows the conceptual model of the evaluation. Limitations for depth, salt content and profile are based on Szabolcs, I. *et al.* (1968, 1969a, b).

Because of its large spatial representativity, the nationwide mapping of soil salinity was based on DKSIS legacy soil profile data, and it was carried out by regression kriging (RK – Hengl, T. 2009). This method permits that environmental factors with exhaustive spatial extension, such as climatic, vegetation-, topographic, soil- and geologic layers can be taken into consideration for the spatial interpolation/extrapolation of the reference data. For delineating the different regions in the „Map of irrigation possibilities" we used thematic layers of (i) properties and water regime categories, (ii) salt content of soil and soil chemistry, (iii) dissolved salt quantity and quality in groundwater. According to soil salinity content categories, the areas were delineated as 1. proposed, 2. conditionally proposed, 3. not proposed for irrigation development.

In some cases, Szabolcs, I. *et al.* (1968, 1969a, b) applied numerical threshold values, and in others relied on their experience, using the geographical and/or genetic soil classification in each category (e.g. based on this, the Hajdúság microregion loess-mantled alluvial fan belongs to the "proposed" category).

We used maximum pH and average salt content of soils down to 150 cm depth. The threshold values were chosen to ensure harmonization with the data set of Szabolcs, I.

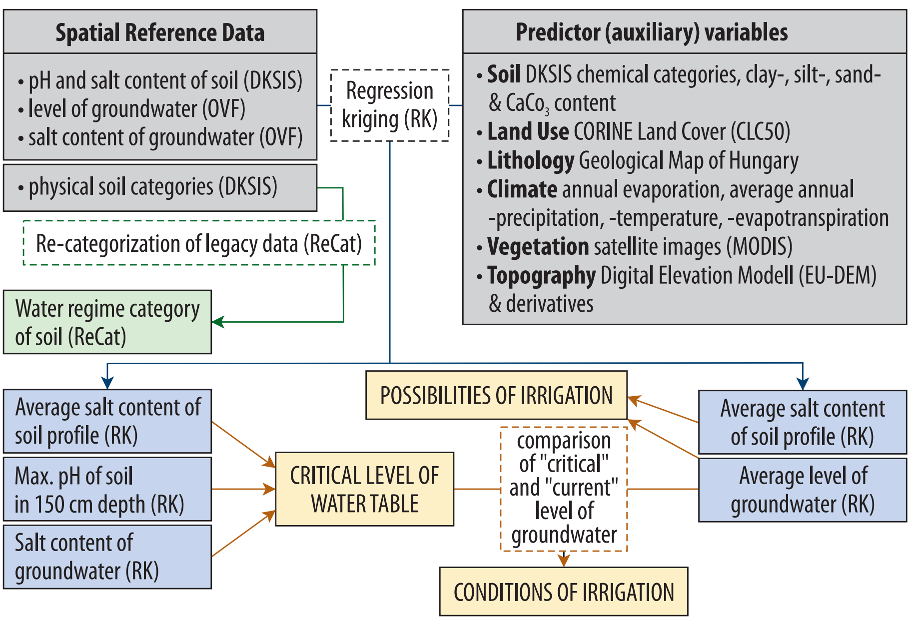

Fig. 1. The conceptual model of critical water-table level-based evaluation

et al. (1968) and the data on the Szarvas plot map (Szabolcs, I. *et al.* 1969b). After the separation of areas that were conditionally suitable for irrigation, the conditions were determined based on the relationship of current "average" and critical groundwater level. The "average" level of groundwater was considered as the mean value calculated from daily groundwater depth records (collected between 2000 and 2013) of the Groundwater Depth Monitoring Network of General Directorate of Water Management limited for the growing season (from April to October). After spatial and error filtering 1,936 observation points remained, whose data were used for further analysis. For spatial inference, proper, spatially exhaustive, auxiliary predictor variables were selected (see *Figure 1*).

Electrical conductivity of groundwater is provided by the Groundwater Quality Records of General Directorate of Water Management. After spatial and error filtering 7,793 well-data remained from the 8,095 sites. We converted their electrical conductivity values into salt content (mg/l) according to the practically accepted approach; using 0.5 as an empirical multiplier applied by OVF Water Quality Laboratory practice (it means that 2,000 μS/cm approximately equals to 1,000 mg/l).

The water regime category map originates from legacy polygon-based map of properties (DKSIS). The legacy map was re-categorized in order to match the water regime categories of soil according to Szabolcs, I. *et al.* (1969a). Salt content, and average level of groundwater as well as soil pH and soil salinity maps were compiled by regression kriging (RK). All mentioned final map products were prepared with 250 m grid size.

The condition of irrigation was determined by the comparison of the 'current' and the 'critical' depth of the water table, because water level shallower than the critical level may result in undesirable processes, such as salinization and alkalinisation. The critical depth of the water table was calculated based on average salt content of the soil profile, the water regime category of soil, salt content of the groundwater and soil pH values.

Evaluation of predicted salt accumulation in the topsoil

The dynamic approach for the prediction of salt accumulation risk is based on the quantification of the salt accumulation processes focusing on the topsoil (0–30 cm), resulting in the „Salinization risk map". Involving the factors which mainly determine the present salinity status of soils, a regression model was set up and, assuming certain water-table rise, the predicted soil salinity status was estimated. The relative differences between the „present" and „predicted" salinity values constituted the basis for vulnerability classification. Based on the main factors of salt accumulation in the topsoil, estimation algorithm was established by multivariate linear regression for salt content of topsoil providing information on the importance of the affecting, background, independent factors. Using monitoring observations, the trend type changes in the depth and salt content of groundwater were also taken into consideration.

Due to large inter-annual changes, for expressing the vulnerability of areas to salinization, the available current soil salt content map is not suitable, but the salt accumulation processes covering longer periods must be quantified. The method used is the determination of the numerical weight (regression coefficients) of the most important factors influencing salt accumulation. First, the multivariate regression equation was developed on the SIMS data (for 670 points) to quantify the effect of processes on the present salt status, in the second step, using the same regression equation, the effect of the assumed groundwater level caused by irrigation was calculated and mapped *(Figure 2)*. The relative differences between the „present" and „predicted" maps constituted the basis for vulnerability classification.

Furthermore, we calculated the areal distribution of salinization risk (vulnerability) categories within the soil productivity classes. The soil type map has been reclassified according to the productivity categorization of MÉM NAK (1979).

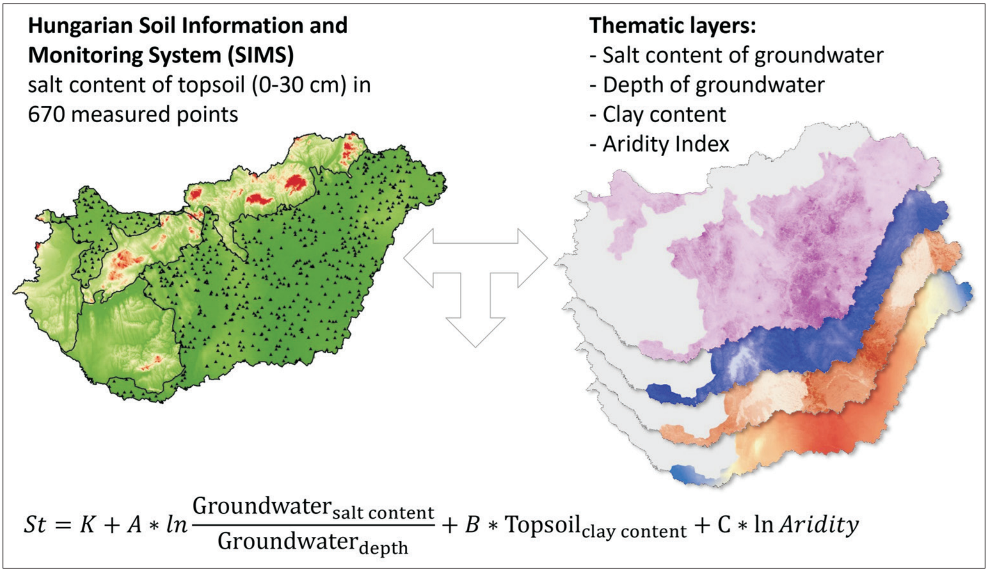

Fig. 2. Conceptual model of processes-based evaluation. In the equation St is topsoil salt concentration; K is constant; A, B and C are regression coefficients, all fitted parameters. Aridity is ratio of annual precipitation to annual potential evapotranspiration.

Estimation of risk of structural degradation

Differential porosity changes (e.g. ratio of macro-pores) within a given soil textural class could be taken as primary indicators of structural degradation and affect the soil water regime, while the accompanying changes in bulk density can indicate the susceptibility for compaction (Rajkai, K. *et al.* 2018). Using profile (MARTHA 1.0) and map-based soil physical databases (www.dosoremi.hu see in Pásztor, L. *et al.* 2017), pedotransfer functions were elaborated for finding correlations between descriptive soil parameters and indicators.

Concerning the nationally available thematic soil maps and the content of MARTHA soil hydraulic database, the main taxonomic soil type, according to Stefanovits, P. *et al.* (1999), organic matter content, carbonate content, pH value and texture classes (USDA) were selected as variables in calculations.

During the assessment of vulnerability for structural degradation, it was supposed, that soils with good structure are not liable to soil compaction. We were looking for a soil-specific index, which can describe this structure stability properly. We examined different structure stability indices (Reynolds, W.D. *et al.* 2002, 2008, 2009; Dexter, A.R. 2004; Ghiberto, P.J. *et al.* 2015; Rajkai, K. *et al.* 2015; De Melo, T.R. *et al.* 2018) derived from MARTHA database, to decide which is the most suitable to describe vulnerability of soil for structural degradation. The relative field capacity (*RFC*) value, the ratio of field capacity to saturated water content (Reynolds, W.D. *et al.* 2008), was finally selected as an indicator for degradation risk. *RFC* is dimensionless, it can indicate the optimum soil structural condition and pore volume distribution. It is calculated, as follows:

$$RFC = \Theta_{pF2.0} / \Theta_{pF0},$$

where $\Theta_{pF2.0}$ is volumetric soil moisture content at pF = 2 tension; Θ_{pF0} is volumetric moisture content at saturation (maximum water capacity = total porosity). *RFC* values can range between

0 and 1. Reynolds, W.D. *et al.* (2009) found that $0.6 \leq RFC \leq 0.7$ values indicate optimum pore volume distribution, and so optimal water- and air-capacity. In case of lower *RFC* values, there are less macro-pores to retain water; while higher *RFC* values show absence of macro-pores, worse air- and water permeability. In both cases, soil productivity may decrease (e.g. less available water or anaerobic conditions for plant roots; limited bacterial nitrification because of waterlogging or lack of air) (Doran, J.W. *et al.* 1990; Reynolds, W.D. *et al.* 2002).

For estimating the vulnerability to soil degradation, the soils were investigated according to the effect of the sum of the basic soil properties considered by the structural properties (Classification and Regression Tree, CRT – Breiman, L. *et al.* 1984). Effects of soil tillage or improper agricultural practice on soil structure could not be taken into account by this classification.

Firstly, we selected data of upper (0–30 cm) plough layers from MARTHA database (except peat soils). Saturated water content and field capacity were estimated (pred_pF0 and pred_pF2.0) from basic soil parameters with pedotransfer functions (SPSS, Classification and Regression Tree, CRT). Category variables were texture class (TX USDA) and soil taxonomic main type of the Hungarian Genetic Classification, ca equivalent classification level to soil orders of USDA Soil Taxonomy (MT), while continuous variables were organic matter content (OM), calcium carbonate content (carb), soil reaction (pH water). After filtering, 710 samples remained for further analysis. An example for the established regression trees is presented in *Figure 3*.

Structural degradation and soil compaction are closely related issues. From predicted water capacity values relative field capacity was estimated (pred_RFC). Pred_RFC was compared with bulk density value and with literature data (Linn, D.M. and Doran, J.W. 1984; Skopp, J. *et al.* 1990; Olness, A. *et al.* 1998; Reynolds, W.D. *et al.* 2002). Categories of vulnerability to soil degradation, considering soil texture, were determined, as follows: 1. highly vulnerable, 2. moderately vulnerable, 3. less vulnerable. In sandy soils too low pred_RFC refers to structural degradation (more macropores, worse water retention); while in case of clayey soils too high pred_RFC mean soil compaction caused by structural degradation (less macro-pores, worse air permeability).

Based on the national digital soil property maps, a new map of pred_RFC was created. The algorithm for creating categories of vulnerability to structural degradation was prepared in R 3.4.0 program (R Core Team, 2017).

Results and discussion

Salt accumulation hazard, secondary salinization

We performed the two types of calculations to gain the maps of risks of irrigation. First, we present the one produced with the steady state model. The evaluation takes into account the salt content of the soil and the groundwater together with the average depth of the groundwater table during the growing season (from April to October) to fulfil the requirements of the critical water-table level evaluation concept (see *Figure 1*).

Map of irrigation possibilities *(Figure 4)* delineates regions with the best condition for irrigation (proposed for irrigation) and areas where the irrigation also possible, but the potential harmful salt accumulation processes must handle by farmers (conditionally for irrigation) The map shows that most of the agricultural land in Hungary is suitable for irrigation, respecting certain aspects.

Considering the relative position of the calculated critical water-table depth and the long term (between 2000 and 2013) average of the groundwater level in the growing season, when the surplus water requirements supposed to be the highest, we compiled the maps of irrigation conditions. Map shows the necessary operations to maintain irrigation *(Figure 5).* Three categories have been distinguished: 1. level of groundwater have to be sunken, 2. rise of groundwater level have to be hindered, 3. level of groundwater have to be regularly controlled, as follows:

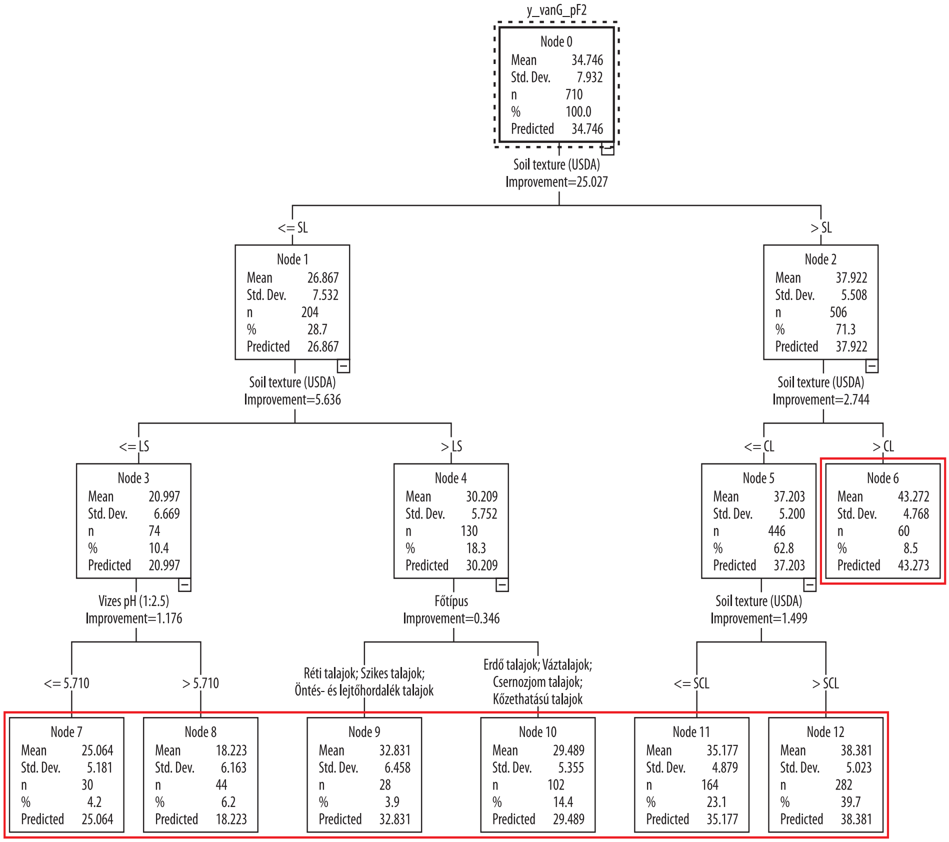

Fig. 3. Water content estimation, an example for pF = 2, classes definition based on soil main type, soil reaction (pH water) and texture class (USDA). M = predicted mean value of the node; STD = standard deviation; n = number of samples, % = percentage of samples used at the node; I = improvement; SL = sandy loam; LS = loamy sand; CL = clay loam; SCL = sandy clay loam. The relation signs in context of the USDA texture classes can be interpreted by the following sequence built in the model: 1 = sand; 2 = loamy sand; 3 = sandy loam; 4 = loam; 5 = sandy clay loam; 6 = sandy clay; 7 = silty clay; 8 = silt; 9 = silty clay loam; 10 = clay loam; 11 = silty clay; 12 = clay.

Lowering the groundwater level is recommended, where the average depth of the groundwater level is shallower than the critical groundwater level.

It is recommended to *prevent rise of groundwater level*, where the average water level of the groundwater level is 0–1 m below the critical ground water level.

Regular monitoring of groundwater level is recommended, where the average depth of the groundwater level is at least 1 m below the critical groundwater level.

The process-based method to compile an irrigation risk map, evaluates the relative differences between the „present" and „predicted" salt status of topsoil. Five vulnerability categories have been distinguished on the "Salinization risk map" (*Figure 6*), as follows:

Non-vulnerable areas: Particularly less clayey (typically sandy) areas and where salinity of groundwater is typically low and there is no salt in the topsoil.

Slightly vulnerable areas: Areas bordering non-vulnerable areas with not significant soil salinity.

Moderately vulnerable areas: These areas are located between the non-vulnerable and vulnerable areas, including typical

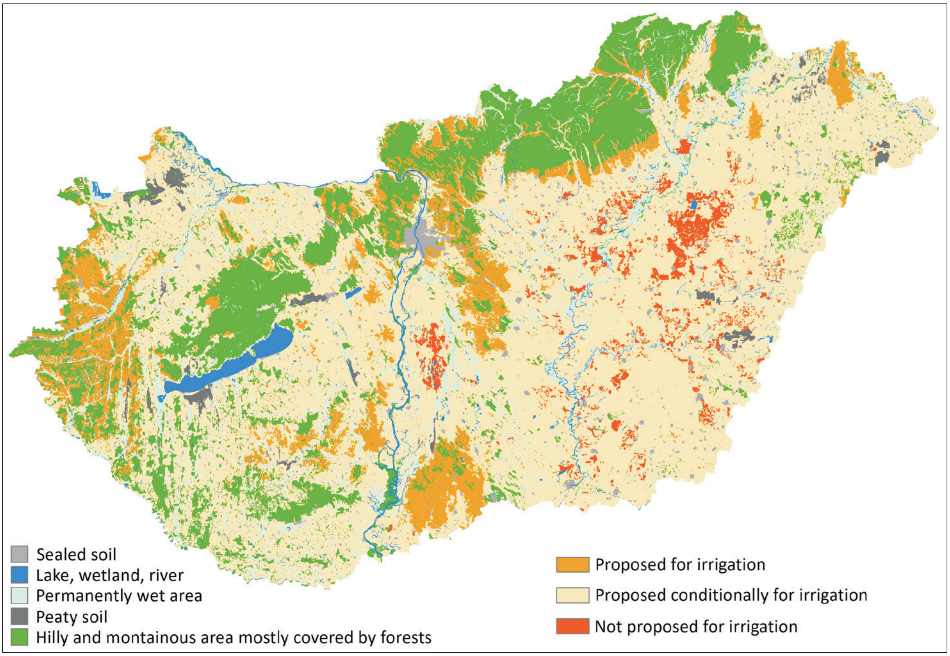

Fig. 4. Map of irrigation possibilities

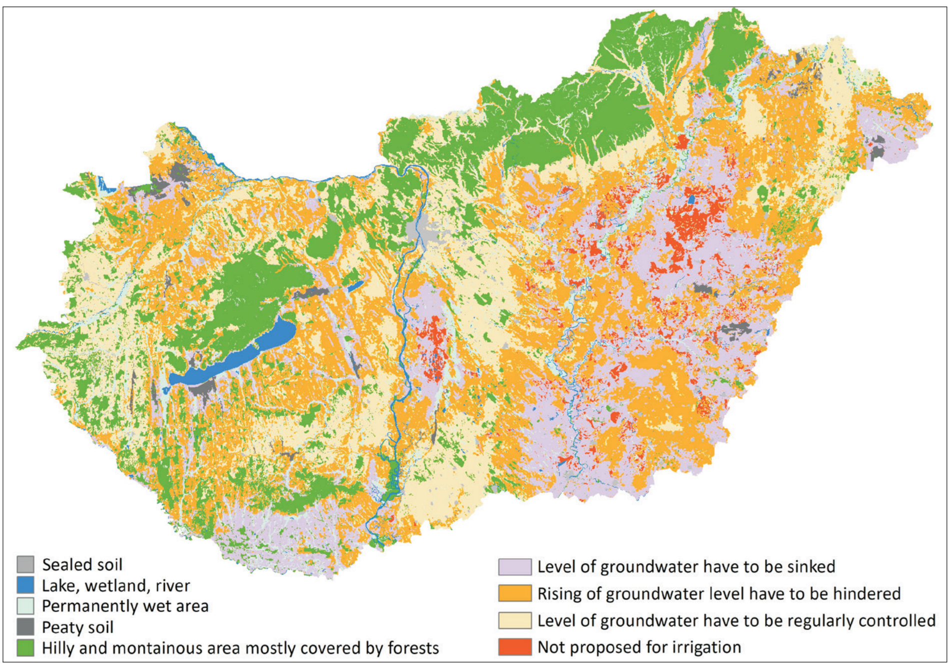

Fig. 5. Irrigation conditions. Map shows the necessary operations to maintain irrigation.

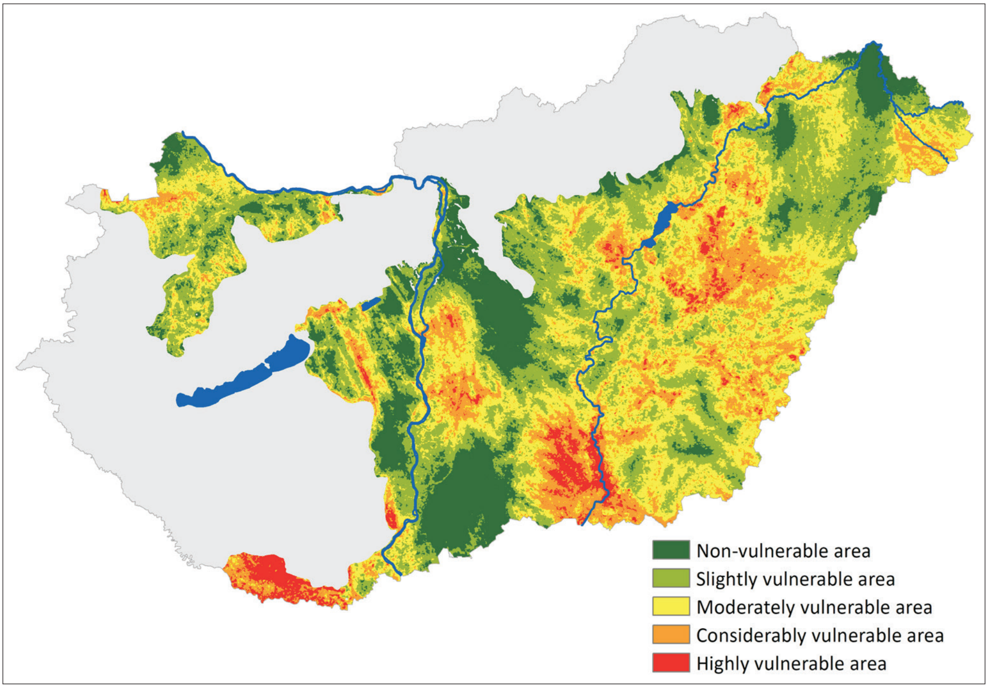

Fig. 6. Salinization risk map

plain regions, mainly in the areas of Tisza, Hortobágy-Berettyó and Körös rivers and have either high clay content, salt content in groundwater or shallow water-table. Certain areas have some salinity in the topsoil.

Considerably vulnerable areas: Most of these areas are salt-affected to some lesser degree than the most saline next category.

Highly vulnerable areas: Most of these areas are currently sodic and/or saline in topsoil. These areas are under the influence of shallow water-table, the salt content of groundwater is high and the soil salt content increases as a result of increasing water-table levels.

Comparison of the "Salinization risk map" *(Figure 6)* with the "Map of irrigation possibilities" (see *Figure 4*) shows that the two approaches give similar results, generally. The territory proposed for irrigation is close the same as the non-vulnerable regions. Moderately vulnerable and slightly vulnerable category (see *Figure 6*) cover 70 per cent of the „to be irrigated conditionally" areas. The sum of highly vulnerable and considerably vulnerable categories covers 20 per cent of it. About 63 per cent of the „not proposed" region belongs to moderately vulnerable or slightly vulnerable category.

The pattern shown in the „Salinization risk map" reflects mainly the independent water-table depth and salinity maps; but effect of clay content and aridity is not dominant. Tóth, T. *et al.* (2002) and Castrignano, A. *et al.* (2008) proved the effect of soil fineness, Zhou, D. *et al.* (2013) considered aridity as influential parameter.

The spatial distribution of salinization risk categories along soil productivity classes

Soil productivity classes serve crop production purposes. Their definition includes basic soil characteristics (taxonomic soil type and soil properties). The lower class number refers to higher production potential. Soil productivity class map was derived from the national soil type map of Hungary (Pásztor, L. *et al.* 2018).

The productivity class V. involves the already salt-affected regions, this class will not be discussed in the further evaluation. Combining the salinization risk and soil productivity maps, we get the regional distribution of the vulnerability categories within the individual productivity classes *(Table 1).*

The productivity class I. covers the most fertile areas, with deep soils and very good water management and nutrient supply, their cultivation is relatively easy ("chernozems-class" in short term). About 30 per cent of its territory belongs to the moderately vulnerable category, on the Csongrádi-sík (Csongrád Plain) geographical microregion in largest extension (*Figure 7.* represents the mentioned locations). More vulnerable is the southern part of Hajdúhát microregion, the loess-part of South Kiskunság microregion and some parts of the Solti-sík (Solt Plain) microregion, which delineates mostly the meadow chernozem areas within the class.

The productivity class II. represents mostly forest soils with good water management and nutrient supply. Less than 20 per cent of its area is vulnerable to secondary salinization, mostly on the southern part of the Pápa-Devecseri-sík (Pápa-Devecser Plain) microregion.

The productivity class III. involves rather heavy soils ("clayey meadow soils") lying on deeper areas of the Great Hungarian Plain, with large water retention but weak conductivity affected by unfavourable excess water, periodically. This group is the most vulnerable to secondary salinization, about 65 per cent of its territory belongs to the moderately/considerable or highly vulnerable categories. Its vulnerable territories follow mostly the riverside areas, the former floodplains along the Tisza, Körös, Maros and Dráva rivers and extend remarkable in the marshy Hanság, Kis-Sárrét and Szatmári-sík (Szatmár Plain) microregions.

Loose sandy soils belong to productivity class IV. The low amount of fine clay particles and organic matter causes low water-holding capacity in these soils that is prone to drought. Through its large amount of macropores, the dissolved nutrients can easily be leached out from the profile. They occupy mostly uplifted geographic position; therefore, the ratio of vulnerable areas is relatively small within this class. The most vulnerable territories concentrate in the eastern part of the Dorozsma-Majsai homokhát (Dorozsma-Majsa Sand Ridge) microregion.

Soil compaction and vulnerability for structural degradation

The estimates for the stability of the soil structure against long-term irrigation have not been incorporated into the national level analysis of soil conditions before. In the estimation of vulnerability, the soils have been grouped according to the effect of all the basic soil properties on the structural properties. The medium or strong vulnerability of the soil structure to degradation is not considered as a negligible cause for irrigation, but the stability of the structure is more dependent on the proposed intensity of irrigation *(Figure 8).*

Table 1. Areal distribution of salinization risk (vulnerability) categories within the soil productivity classes

Vulnerability category	Soil productivity class (area, ha)				
	Chernozems	Forest soils	Heavy soils	Sandy soils	Salt-affected soils*
Non-vulnerable	368,995	95,004	125,086	286,872	10,615
Slightly vulnerable	670,522	82,664	562,325	387,789	145,049
Moderately vulnerable	507,682	34,074	709,640	151,408	327,737
Considerably vulnerable	185,586	5,570	466,777	56,157	216,932
Highly vulnerable	14,431	1,903	131,352	25,529	38,722

*More details are provided in the text.

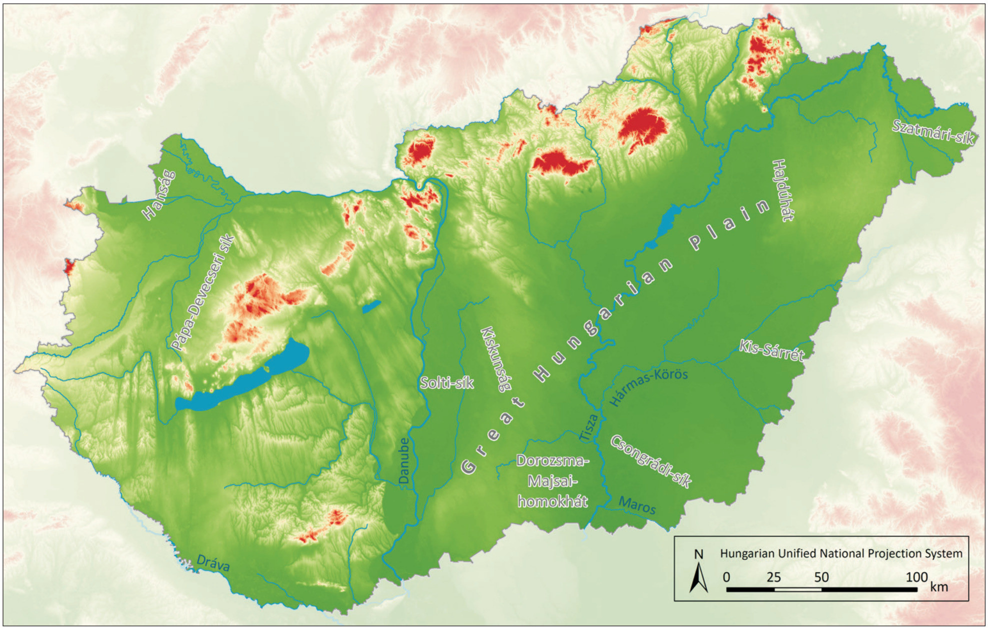

Fig. 7. Relief and hydrography overview map of Hungary with the locations mentioned in the salinization risk (vulnerability) results section

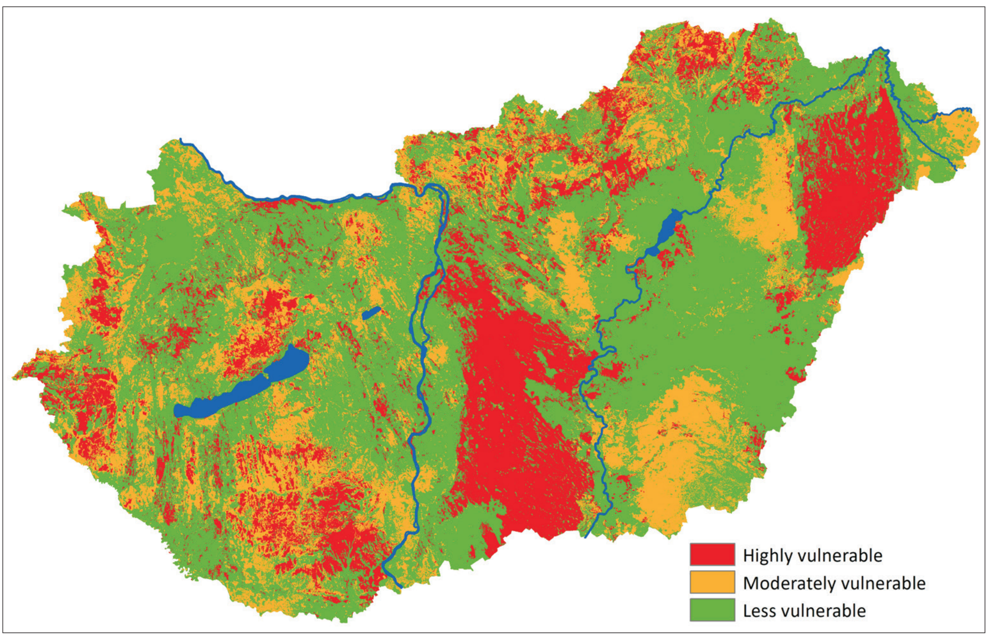

Fig. 8. Vulnerability of soils for structural degradation

Three categories were distinguished on the map of "Vulnerability of soils for structural degradation":

1. Highly vulnerable soils for structural degradation: these are the soils whose structure can easily degrade as a result of even short-term low-dose irrigation; they become prone to compactness, disaggregation, crusting. After that structural elements break down, fine particles (clay and fine silt fraction) move/are leached down into deeper/lower soil horizons, fill the pores, promoting soil compaction.

2. Moderately vulnerable soils for structural degradation: these are the soils whose structure may degrade due to longer and/or more intense irrigation. Soil can disaggregate, crusting and compaction can occur. Those soils belong to this group, which have medium strong structure, medium textured. Their colloids and humus contents are between the two other categories.

3. Less vulnerable soils for structural degradation: these are the soils that retain their good structural status through longer and/or intense irrigation; they tend to be less susceptible to slaking and compaction and disaggregation. Those soils belong here, which are mainly rich in colloids and humus, strongly structured, and heavy-medium textured.

This index of vulnerability to structural degradation is only one point of view to indicate soil's liability to physical failure. The index shows on which soil structural degradation can occur due to even a little amount of irrigation water, and which soils are more resistant.

If we examine current structural conditions of soils, and what can be the result of long-term irrigation, we will get another point of view. For example, an upper layer of humus-rich sandy soil has weak structure, its structure elements easily fail even after a small dose of irrigation water, and there is a decreasing volume of micro-pores. However, this structure failure is not excessive, RFC value does not drop much; we can have similar yield on this soil with continuous irrigation and nutrients supply. In case of a chernozem soil with good structure, as the result of continuous irrigation, with unsuitable doses, soil structural units can disaggregate slowly, and this change would be drastically great/harmful (in structural condition, water- and air-management). Consequently, the rate of harmful effects can be very diverse, and contrasting opinions might be formed on it.

Comparison of the vulnerability map for structural degradation with the map of conditions for irrigation shows that the half of the areas proposed for irrigation are highly or moderately vulnerable for structural degradation.

Conclusions

Nationwide planning of irrigation can be made only if we have spatially exhaustive maps and recommendations for the different areas. The presented irrigation risk estimations focus on soil-related threats and aim to support national level decision-making. We applied both of steady state and process based calculation methods for the spatial identification of potentially affected areas. Novelty of this study lies in:

– to actualize and spatially extend the earlier developed critical-level based calculation method in digital data processing and mapping environment,
– to develop two calculation methods for mapping salinization risk,
– to incorporate estimations for the stability of the soil structure against long-term irrigation, which have not been used in national level analysis before.

The computational framework shown is suitable for compiling more detailed maps, which can serve the local demands better, if additional data with sufficient thematic and spatial resolution are available.

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A novel approach for mapping WRB soil units – A methodology for a global SOTER coverage

Endre DOBOS[1], Péter VADNAI[1], Károly KOVÁCS[1], Vince LÁNG[1], Márta FUCHS[2] and Erika MICHÉLI[2]

Abstract

Traditional soil maps present soil information in the form of categorical classes of soil types classified on the appropriate level of the applied classification system corresponding to the scale. Soil complexes and associations have been used to describe polygons. This kind of data structure is useful to characterise an area by explaining its soil resources. However, it is difficult to convert these complex categorical units into a simple digital variable, the usage of this kind of data in a digital environment is limited. Users often need single properties instead of the complex classes. Additionally, the problem becomes more complicated when soil information of different origin, based on different classification systems has to be integrated into a common, harmonised database. The presented methodology is part of the efforts to develop a global SOTER (World Soil and Terrain database) coverage and contribute to the global soil observing s as part of the Global Earth Observing System of Systems (GEOSS). The aim is to determine and map the relevant soil properties, horizons and materials following the diagnostic concepts of the World Reference Base (WRB) for soil resources and derive the occurrence probability of soil classes (WRB reference soil groups) of certain spots with the application of remote sensing and digital soil mapping tools. The developed method is referred as the e-SOTER approach and is capable of producing a stack of soil diagnostic element layers with the likelihood of their occurrence within each pixel and a layer of WRB reference soil groups (RSG). This new approach may provide better input for modellers and predict the spatial continuum of the soil cover in a much better resolution than the traditional polygon based approaches. At the same time the diagnostic elements, as building blocks of the classification systems, help the correlation of the national soil classes into integrated databases and maps.

Keywords: soil types and classification systems, soil classification methodology, World Soil and Terrain database, global soil observing, WRB reference soil groups

Introduction

Soil is a continuous cover on landscapes. Appropriate use of this natural resource requires knowledge of its spatial heterogeneity. The physical, chemical and biological properties are distributed differently in the land surface. These properties are often linked together to specific combinations as a response to the soil forming environment (Glinka, K.D. 1927; Jenny, H. 1941). The commonly occurring soil forming process associations have been used to define soil classification categories. Guy Smith was the first who recognised the results of these processes regarding diagnostic features having measurable properties and quantitative characteristics to classify soils (Eswaran, H. 1999). The early and later editions of Soil Taxonomy (Soil Survey Staff, 1999), the legend of the FAO UNESCO Soil Map of the World (1974–1981), the WRB (IUSS Working Group WRB, 2007a, b) and several modern national systems are based on these diagnostic principles. This approach

[1] Institute of Geography and Geoinformatics, University of Miskolc. H-3515 Miskolc, Egyetemváros. Correspondent's e-mail: ecodobos@uni-miskolc.hu

[2] Department of Soil Science and Agro-chemistry. Szent István University, H-2100 Gödöllő, Páter Károly u. 1. E-mails: fuchs.marta@mkk.szie.hu, micheli.erika@mkk.szie.hu

is still valid and represents the state of the art knowledge of soil science.

On the other hand, soil mapping requires several generalisation steps and compromises to dissolve the within-class heterogeneity and create classes that are valid, homogeneous and meaningful, of which these classes have been used for soil mapping. Mapping and interpreting soil classes need soil experts to extract certain soil properties or property associations to stipulate the proper use of soils. It is especially true in case of small scale datasets and maps, when not only the soil property association (soil types) but associations of the soil types (soil associations or complexes) have been used to characterise the area.

Any use of these maps requires the disaggregation of the information and the allocation of the soil properties to specific environmental conditions within the polygon. It used to be done by soil experts using mental soil-landscape models. However, users from other fields of science have difficulties in interpreting the content.

The SOTER approach introduced the application of physiographic and – when it was available – lithological information to delineate the spatial units of small scale maps and datasets (ISRIC 1993; van Engelen, V.W.P. and Wen, T.T. 1995; European Soil Bureau Scientific Committee, 1998; King, D. *et al.* 2002). The soil information is assigned to these terrain units. These geographic units are difficult to be used for any modelling activity, because no spatial disaggregation of the soil type association can be done to geo-locate, spatially define the information.

The past three decades has changed the world of cartography and database development methodology. GIS tools have been developed to analyse and present spatial information more efficiently. In the meantime, a tremendous amount of digital spatial datasets has been collected and compiled, such as digital elevation models and satellite images providing high-resolution environmental covariates for soil mapping. Digital soil mapping has become a very effective tool in soil science, and several applications have been published (Dobos, E. *et al.* 2000, 2006, 2007, 2010, 2013b; Worstell, B. 2000; McBratney, A.B. *et al.* 2003; Lagacherie, P. *et al.* 2006; Szatmári, G. *et al.* 2013; Pásztor, L. and Takács, K. 2014; Sisák, I. and Benő, A. 2014; Szatmári, G. and Pásztor, L. 2016). Soil data is needed for several applications, but only in a format that can be integrated into the existing models. The majority of soil data users require data in raster format with values of certain properties, like pH, clay content or soil organic matter content. Some of these variables are used as it is, as direct inputs into the model, while others are used to estimate complex soil features and properties, like diagnostics, features and horizons. These sophisticated features, like the WRB diagnostics, present valuable information for several applications. Taking the groundwater impact as an example: information on the presence of temporal water saturation in the soil occurs as very important for several environmental, agricultural or civil engineering applications. Water saturation is the function of several soil and environmental properties, such as climate and terrain conditions and soil properties like compaction, total and differential porosity, bulk density, depth to the groundwater, dynamics of its fluctuation etc. We need to know all soil and environmental properties to predict their collective impact on soil. In contrast, soils showing gleyic properties prove that all the required conditions are present at the same time to develop hydromorphic impacts on the soil.

The WRB diagnostic horizons and other diagnostic elements represent a set of well-defined characteristics of a soil horizon. Each of them is important to describe the soil system and can be interpreted to provide information on the proper use and functions of soil. The established (predicted) presence of these horizons and features gives direct answers to the most common questions with no need for further processing, calculating or interpreting several properties to derive the information needed. Therefore, WRB diagnostics have been already used in some applications (Dobos, E. *et al.* 2010; Liess, M. *et al.* 2012; Pásztor, L. *et al.* 2013).

The goal of this study was to develop a novel approach to present complex soil properties in the form of WRB diagnostics that can be used efficiently for modelling using georeferenced soil data and auxiliary digital data sources, like remote sensing and digital elevation model (DEM) data. The developed method may support the completion of the global coverage of the SOTER database by providing a digital soil mapping (DSM) toolset to create harmonised soil information for the SOTER polygons. This method is referred as the e-SOTER approach and produces a stack of soil diagnostic property layers showing the likelihood of their occurrence within each pixel and a layer of the Reference Soil Groups (RSG) of the WRB.

Methods

The overall framework

The e-SOTER approach is based on the major building units of the WRB classification system such as the diagnostic properties and horizons (DPDH). It attempts to estimate the spatial occurrence probability of DPDHs using remote sensing, digital terrain data and pre-processed legacy data - as training dataset. As the WRB includes numerous diagnostics, a limited set of significant units has to be defined by an expert group based on the existence and significance of horizons, properties and materials of the target area. Training datasets for this group of diagnostics are derived from legacy data. Each training dataset consists of points or areas with known existence or absence of the property in question. Therefore, using these training datasets for classifying a complex MODIS/SRTM based image results in numerous continuous layers for each property having the probabilities of the existence of the diagnostic property. The major advantage of this approach is that it provides the needed thematic information on essential soil properties such as; texture, organic matter, salt content etc. Additionally, using these DPDH layers, a WRB-based simplified classification scheme is developed to identify the WRB soil types for each pixel. The success and detail of the approach depend primarily on the quantity and quality of the input training dataset.

The workflow of data development has the following major steps:
- Development of important input physiographic and parent material layers for the classification – landform, bare rock, the texture of the unconsolidated parent material (*Table 1.* lines 1–4);
- Definition of the significant WRB diagnostics (properties and horizons – DPDH) needed to characterise the major soil properties and features of the mapped area (*Table 1.* lines 5–16);
- The collection of legacy data (soil profiles or large scale soil maps) and the development of the training datasets;
- DSM procedure to develop the layers of the WRB diagnostics (properties and horizons);
- The definition of the classification rules to define the WRB RSGs.

Table 1. The list of important terrain, texture and WRB properties, diagnostics and horizons (DPDH) in the gridstack

1	Terrain type with 5 classes (stratification map): 1. fine plain 2. coarse plain 3. hill 4. mountain 5. water
2	Consolidated-unconsolidated image
3	Texture image
4	Bare rock image
5	Spodic Horizon Class Probability
6	Argic Horizon Class Probability
7	Cambic Horizon Class Probability
8	Vertisol Class Probability (only Vertisol vertic horizons)
9	Salic Horizon Class Probability
10	Natric Horizon Class Probability
11	Gleyic-Stagnic-Reducting conditions Class Probability
12	Mollic Horizon Class Probability
13	Calcic Horizon Class Probability
14	Calcisol Class Probability (only Calcisol calcic horizons)
15	Dystric Class Probability
16	Eutric Class Probability

The study area

The pilot area is located in Central Europe and covers the territory of Austria, Hungary, Slovakia, Czech Republic, Southern Poland, and a small part of Germany and Romania. This window has been chosen to cover the Central European pilot area of the e-SOTER project *(Figure 1)*. The final area is much larger than the pilot; it follows the tile borders of the SRTM (Farr, T.G. and Kolbrick, M. 2000) and MODIS images that fully includes the e-SOTER pilot. Training data has been available only for the pilot window and the territory of Hungary.

The terrain and the soils of the area are quite variable (Pásztor, L. *et al.* 2018). It includes parts of the Alps, the Carpathian mountain range, the Czech-Moravian Mountains, the Pannonian Basin and the southern, hilly and flat region of Poland. The parent material varies as all kinds of consolidated siliceous and carbonaceous rocks occur the area, together with Holocene alluvial and aeolian sediments, and Pleistocene glacial and periglacial materials. The soils on the lowland are mainly Chernozems, Vertisols, Arenosols, Gleysols and Calcisols, while on the hilly and mountainous areas Luvisols, Cambisols, Stagnosols, Regosols and Leptosols are the dominant ones.

Covariates used to derive the thematic layers

To strengthen the performance of the classification, multi-temporal images of MODIS bands were compiled into a 55 layer image representing the visible, Near Infra-Red (NIR), Mid-infrared (MIR) and thermal bands to capture the temporal environmental conditions and changes that reveal to surface conditions. Multi-temporal 8 days MODIS composites were used, five dates evenly distributed over the vegetation period:

– MOD09A1: Band 1-2 (250 m resolution)-7 (Layers 3–7), 500 m resolution;
– MOD11A2: Band 31-32 (Layers 9–10), LST (Land Surface Temperature) Day (Layer 1) and LST Night (Layer 5), 500 m resolution.

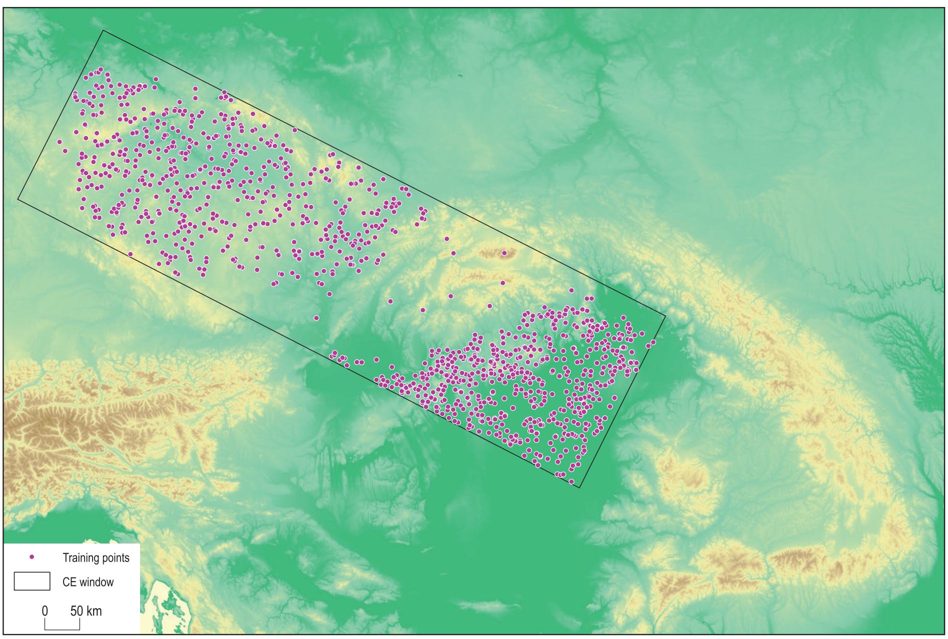

Fig. 1. The pilot window and the distribution of the profile dataset for the Central European window

However, the 55 layers have a significant portion of overlapping information, redundant information in the images, hence a Principal Component Analysis (PCA) was used to decrease the number of input images and de-correlate the information of the bands. The first 15 PCA components were maintained and incorporated into the final image.

Previous studies also suggested using surface temperature information, like the thermal bands of the MODIS (Bands 31, 32) and the LST (Land Surface Temperature) products (night and day) that have been derived from them. The daily temperate fluctuation is a function of the thermal capacity of the surface material, which is the function of the kind of material, texture, colour and water content; primarily the factors of key interest to the study. Therefore, a new normalised band combination was developed and added to the PCA image set for each date. The daily temperature difference was calculated by simply subtracting the LST night from the LST day, and the values were multiplied with the ratio of the LST_{max} / LST_{day} to reduce the effect of the climatic variation due to the difference in potential energy intake from the sun. (Note: LST_{max} = LST maximum value for the whole area.)

There were many attempts recorded in the literature to use band ratios to identify certain lithology classes or to highlight lithology differences in Landsat images. These band ratios were adopted to MODIS and were derived for each of the five dates, resulting in 15 other images, that were added to the final image. Three band ratios adopted after Drury, S. (1987) and Segal, D. (1982) of 6/2 (ferrous minerals ratio), 1/3 (iron-oxide ratio) and 7/6 (clay mineral ratio) were created to represent lithological variations better.

SRTM (Farr, T.G. and Kolbrick, M. 2000) data were used in combination with the MODIS derived layers as well. The basic parameters were the following:

- Elevation (sinks are filled up to a certain level);
- Slope per cent;
- Relief Intensity;
- Potential Drainage Density (Dobos, E. and Daroussin, J. 2007);
- Groundwater level (developed via the interpolation of the SRTM derived drainage network points heights and subtracted from the original elevation values);
- Topographic Wetness Index;
- Upland/Lowland: (elevation range/2 + elevation min – elevation) for a 10 pixels radius circle;
- Convexity (not added to the basic image, used only for the colluvial image derivation).

The listed derivatives are either used in the SOTER methodology already or believed to add significant information for differentiating between the classified parameters. The SRTM images were spatially degraded to the level of MODIS resolution, the final resolution of the image was 456 m, partly to stay close to the original resolution of the MODIS and partly to be multipliable by the SRTM resolution.

Besides of the 43 layers (15 PCA layers, 8 SRTM derivatives, 5 normalised LST difference images and 15 band ratios), three further layers were added to the image to represent the climatic variability. These were the images of Easting and Northing, which defines the geographic location, and the distance from the sea. With these extra 3 layers, 46 layers image was developed and used for the classification.

The development of input layers for the final classification

The SOTER physiography layer development

The SOTER approach is based on the assumption that the landform and the parent material are the most critical factors of the soil formation when working within a relatively small land surface area, like a SOTER polygon, in which the natural macroclimatic variability is negligible. Therefore, the major portion of the climatic variability is due to the terrain that defines the meso and microclimate as well. The vegetation develops in the function of terrain, climate and soil, so the majority of the vegetation variability is already explained by them. This assumption is the basis for the pre-stratification of the area, the physiography and simplified parent material classes that defined the homogeneous units. Five classes have been distinguished: water, mountain, hill, and two plain classes, namely the fine and coarse plains. The terrain classification used the SRTM-based, modified physiographic classification of the SOTER developed by Dobos, E. *et al.* (2007, 2013b) and is shown in *Figure 2.* Elevation and relief intensity variables were used to separate the mountain, hill and plain classes. The plain class was further divided into fine and coarse plains using the MODIS and LUCAS based texture classification image. The fine plain area has clay or loam texture. The coarse plain is the sandy and gravelly textured plain area. The texture class database development used the method defined by Dobos, E. *et al.* (2013b). The terrain/parent material based pre-stratification of the European window is shown in *Figure 3.*

Parent material image-set development

Parent material is vital to define the soil associations within the SOTER units. However, it is often difficult to compile harmonised parent material datasets from legacy data.

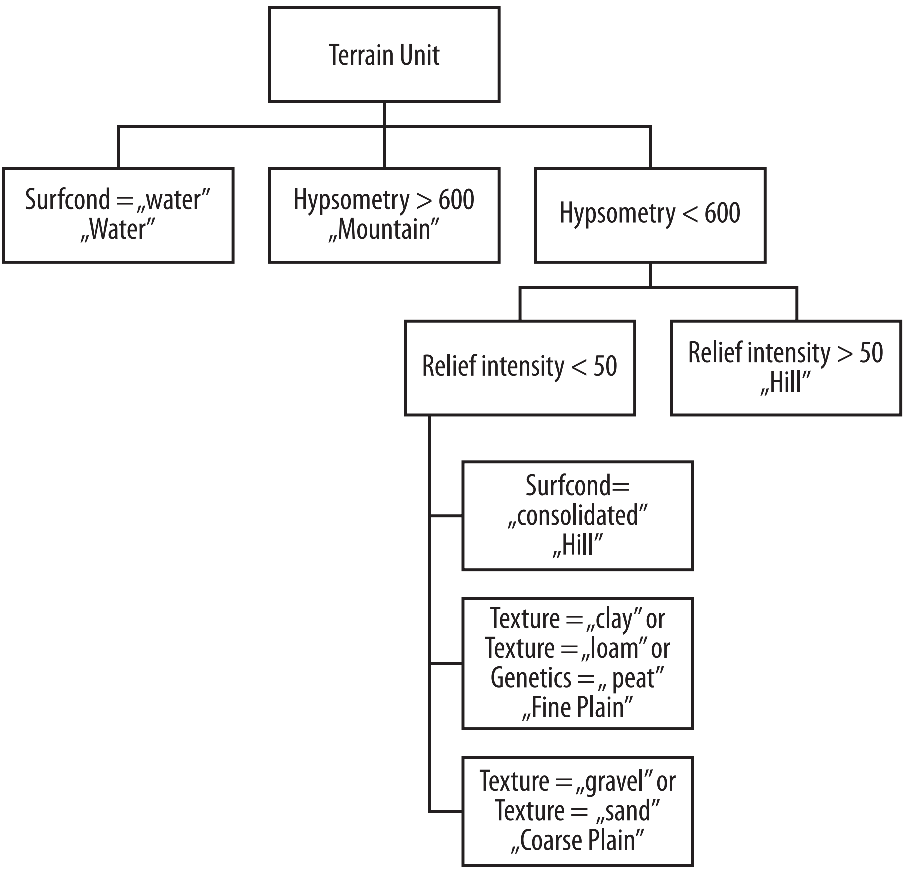

Fig. 2. The decision tree for the pre-stratification of the study area. The relief intensity value is calculated for a 1 km diameter circle area.

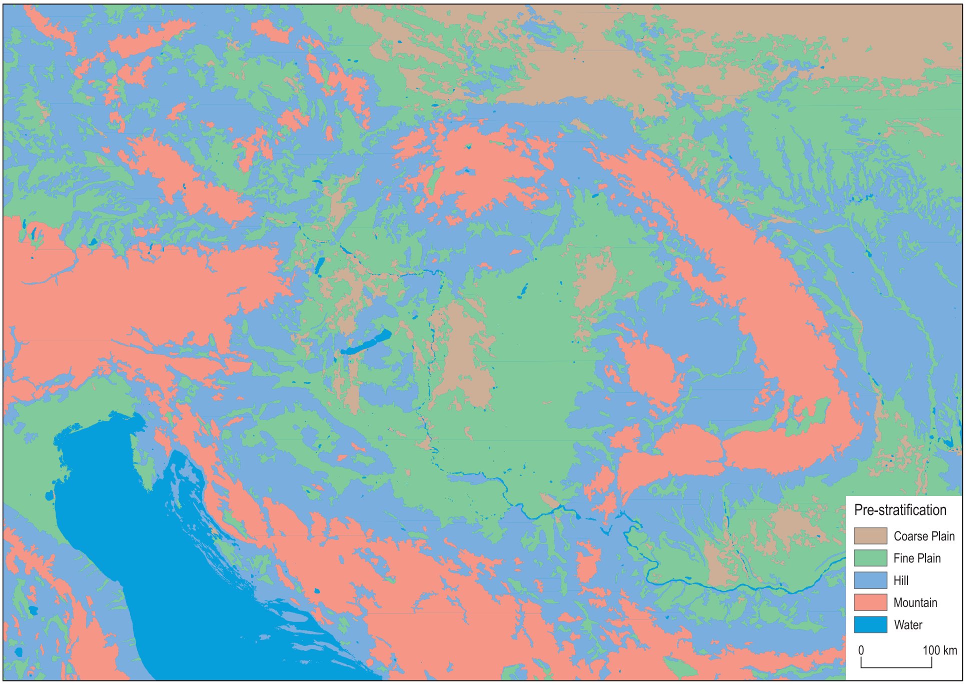

Fig. 3. The terrain/parent material based pre-stratification of the Central European window

Our approach differs from the traditional, legacy data-based approach, where existing surface geology data of different origin is used to define the soil forming units. Our approach comes from the geomorphological approach. The assumption is that different parent materials (PM) have different surface morphology, therefore part of the properties can be estimated by geomorphometric tools. The term "parent material" is used herein a simplified way. The approach is a digital soil mapping procedure based, modified SOTER approach developed within the e-SOTER project by Dobos, E. *et al.* (2013b).

This study is using only the first two levels of the classification tree, namely the consolidated-unconsolidated layer – complemented with the bare rock layer – and the texture, including the diagnostic organic soil material as a separated class. The calcaric nature of the material is handled later in the DPDH classification by their nature.

The final parent material image is a combination of the consolidated/unconsolidated image (a), the bare rock surfaces for the consolidated parent material areas (b) and the texture classes for the unconsolidated areas (c).

a) Consolidated/unconsolidated areas – Unconsolidated material is defined here as a loose inorganic/organic material, that is by nature, accumulated/deposited in a deeper stratum by wind, water or ice (fluvial, estuarine, lacustrine, marine, glacial, aeolian) or by mass movements (like the colluvial materials). The consolidated material – as it is defined here – is the solid rock and its shallow weathering residuum, having mainly the typical mountain soil associations like bare rock/Leptosol/Cambisol, and by genetics, it can be eluvial (locally weathered residuum), colluvial or bare rock. The widening of the content with the weathering residuum is an unavoidable compromise because the existing soil maps with parent material information for this kind of areas describe only the underlying rocks and gives no information on the properties of the weathered material. This statement was concluded by the authors; it is still not commonly agreed.

Maximum likelihood supervised classification algorithm using the combined image of 46 layers was applied to derive the consolidated/unconsolidated image (Dobos, E. *et al.* 2013b). There are only stochastic relationships between specific terrain parameters and the consolidatedness of the PM. It is also true for the RS images, especially in the temperate and tropical zones, when the vegetation masks out the PM signal of the images.

Training data was limited for the window as only 10 per cent of the whole area was covered with legacy data. Training areas for the Czech Republic and the Hungarian part of the window were used. The data sources were interpreted in the training areas for the classes defined. The consolidated and unconsolidated parts are handled and classified differently from this point.

b) Bare rock image – The bare rock classification was done using an NDVI (Normalized Difference Vegetation Index) image generated from the peak of the vegetative period, like summer in the Central European (CE) window, when strong vegetation cover is expected. Only areas having no soil and thus vegetative cover are expected to have very low NDVI value. A threshold was set by selecting known areas with bare rock and the corresponding; representative NDVI values were identified and used for threshold the NDVI values. This value and the procedure in general works very well in the temperate and tropical zones, it has been tested for France/United Kingdom and Southwest China as well (Dobos, E. *et al.* 2013b).

c) Developing the texture class layer – The most critical part of the procedure is the training data. The optimum case is when relatively high-resolution training data is available with well defined, none overlapping classes. 1:100K to 1:250K data sources are commonly available for the developed part of the World, which contain aggregated but still concrete classes (not associations). These data sources can be used as direct inputs for the supervised classification.

The texture classification was done the same way as the consolidated/unconsolidated layer, using the 43 layer combined image and training data for the supervised classification. The legacy training set for the training area was the same as well, but this dataset was complemented by the LUCAS dataset (Tóth, G. *et al.* 2013; Orgiazzi, A. *et al.* 2018). The sand, silt and clay percentages of the LUCAS, TIM (Várallyay, Gy. *et al.* 1995; Várallyay, Gy. 2012) and the Czech topsoil datasets were converted to texture classes and used for the supervised classification. The texture layer is shown in *Figure 4.*

The definition of the significant WRB diagnostics (properties and horizons) and the classification rules to define the soil classes

Typical soil types for the four terrain/parent material classes and their corresponding diagnostic horizons and properties were defined by expert knowledge and listed as required information layers for the soil characterisation. This list of the selected DPDHs was then compared with the local legacy database to test for missing DPDH or real existence/significance of the selected DPDHs in the database. New DPDH was added to the list when the legacy data proved its importance, or DPDH was removed when the legacy data did not contain information on the feature, or the frequency of occurrence was too low to support the classification algorithm. In some cases, the DPDH was kept, even if the data was not supporting its importance, but the experts flagged it as an important factor for the classification.

The last step of the procedure was the classification of the WRB reference soil groups (RSGs). A WRB classification tree was developed to estimate the most likely RSG for each pixel. A nested conditional function was developed to classify/define the corresponding RSG for each pixel using the variables of the stratification image and the DPDH images – described below. This classification tree depends strongly

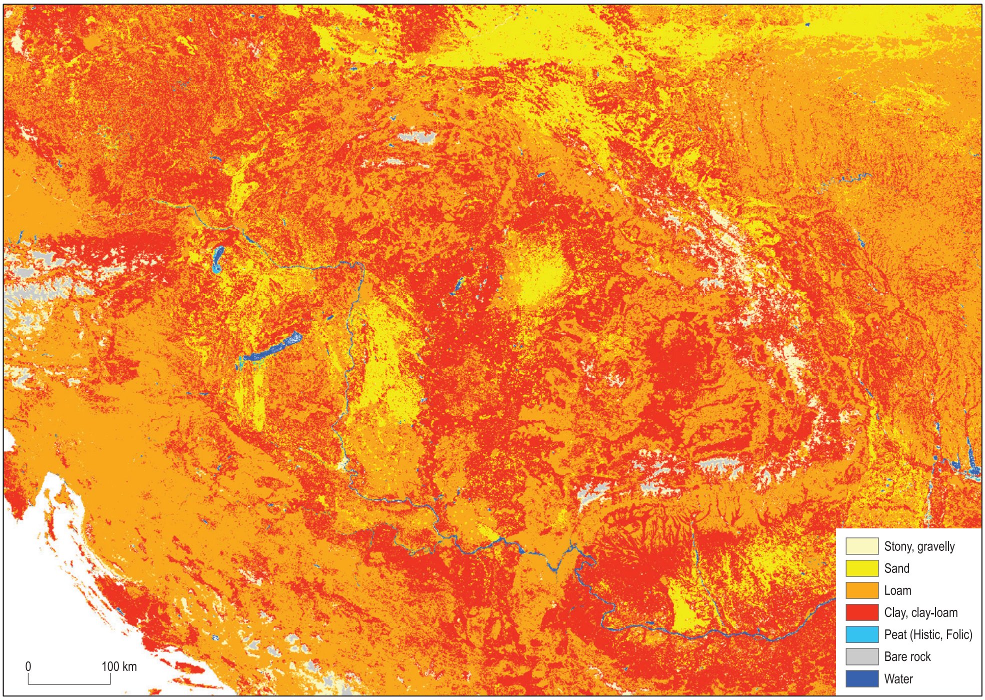

Fig. 4. The classified texture classes for the pilot window (Dobos, E. *et al.* 2010).

on the detail and content of the legacy data. The one shown below was developed for the Central European window and was adapted to the available set of soil information. The more complete soil data, the more detailed classification tree and the more refined RSG classes can be elaborated. On the other side, similar or related soil types may need to be combined into more complex units when input data is limited.

This classification tree was developed specifically to the Central European soil associations and data availability conditions of the region. Other regions may require different trees with different terrain and DPDH elements and different rules explaining the soil formation. Narrowing the potential variability to the ones occurring in the area simplifies the classification tree and makes it more efficient and site specific. However, this methodology requires strong local knowledge and understanding of the geographic distribution of the soil resources and the major driving forces of the genetics of the soil types.

One may recognize that Fluvisol, that should be common in the area, is not included among the RSG classes. The reason is that all major rivers of the region have been channelized and the natural floodplains have been narrowed by dike systems built along the rivers. The remaining active floodplain has been cut to only a 100 m or narrower strips along the river, which is not wide enough to present on the map.

The classification tree followed the WRB key RSG order to make sure that the final categories match the WRB classification. For example, if a soil occurs on the plain area and has a mollic or chernic horizon and also has a clay, heavy clay texture – which is very common on the Great Hungarian Plain – the soil keyed out as Vertisols, while the remaining ones have classified to Chernozem/Kastanozem RSG.

Development of translation algorithms and correlation tools for the harmonization process

The legacy soil data originated from different sources (i.e. national and international data sets) is usually very variable, because the collection, determination and classification of it are based on various methodologies. For international projects, European and global initiatives using data from diverse sources, preliminary harmonization is necessary to provide a standardized input dataset for further research.

For soil data harmonization international standards are provided. Within the European Union, the harmonized master horizon designation, subordinate characteristics and site descriptions follow the 2006 edition of the FAO Guidelines for soil description (FAO, 2006). The classification of soils and the related diagnostic horizons, properties and materials are described and coded according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2007a, b). The success of harmonization largely depends on the quantity and quality of the input datasets.

In many cases, the number and completeness of field observation and laboratory data is insufficient for proper correlation. The determination of the WRB diagnostics, Reference Soil Groups and qualifiers often requires morphological, chemical and physical soil data as well. Simplification of the requirements and expert judgment is often needed to overcome the shortage in information.

In this study a computer assisted determination of the diagnostics was applied for all datasets with simplified requirements of the WRB (2007a, b). The simplification was adjusted to the availability of the required information. In many cases, even the simplified requirements were not available and expert judgment was used to determine the presence or absence of the diagnostics. Since many of the diagnostic features require morphological criteria that are not commonly part of the legacy data sets, a significant portion of uncertainty is introduced into the procedure.

In order to generate the training dataset for the image classification 31 simplified algorithms for the WRB diagnostic horizons, properties and materials and 29 simplified algorithms for the WRB qualifiers were performed on the harmonised dataset. The output database contained simple information, such as the presence or absence of the given diagnostic criteria for each profile. Classification was performed only when sufficient information was available for the given criteria to avoid additional uncertainty of the training dataset. Due to the lack of information in the database a large number of profiles were necessary to generate a suitable number of training points for each DPDH.

The collection of legacy data and the development of training datasets

The representative datasets could be points or polygons having unique identifier for each of the objects. A Microsoft Excel sheet was created with the identifier column and one column for each selected DPDH. Experts derived the existing DPDHs for each object based on the provided classification units and the measured properties of the legacy data. A value of "1" was assigned to each object, when the DPDH in question was existing, and a "0" value for non-existence. The cell was left empty when no decision could be made. Therefore, two classes were created for each DPDH, the existing class and the non-existing one; while the empty ones were not used for the classification of the specific DPDH.

Additional data points were needed when the resulting number of points for the DPDH was insufficient. Due to the matrix inversion steps used in the calculation process of the image classification, the number of training pixels for each class used in a maximum likelihood classification procedure has to be at least one more than the number of image layers used for the classification. In our case, the image had 46 layers, so the minimum number of training pixels had to be at least 47. In case of less than 47 training pixels for the classes, the legacy data points were extended "artificially" to a larger region using statistical thresholds of Euclidian distance for the surrounding pixel values to make sure that similar pixels are involved into the training procedure. A similar procedure to transform the point dataset into a raster with a size of 1 km^2 was used as well, and the whole area of the pixel was used as a training area. This latter approach is simpler, however unavoidably introducing unsupervised uncertainty into the procedure. Therefore, it was used only when large numbers of points were involved. For the Central European window 1091 profiles were available. The distribution of the profiles is shown in *Figure 1.*

The development of layers of DPDH using image classification procedures

Probability classifications for the DPDH were done using the MODIS/SRTM image and legacy data based training dataset. Signature files for each DPDH were created from the training dataset and used for Class probability classification. The classification was performed using the ClassProb command of the ArcGIS software setting the range of values between 0 and 100, where the value of 50 means the equal possibility of the two classes (existing or missing DPDH), the higher values mean higher likelihood for the existence, while the lower for the missing DPDH. The mapped area was pre-stratified into the terrain/PM classes described above and the classification of the DPDHs was done simultaneously and individually for the four regions. In the end, the 4 (5 with the water class) classified images of the same DPDH were mosaicked together to create the final probability image for each DPDH.

Validation methodology

The details of the validation procedure have been described by Dobos, E. *et al.* (2013a). The final dataset has several DPDH probability layers and some categorical ones, like the RSGs and the texture classes. The percentage value of the occurrence probability can be taken as a probability of being correct in the classification, or – having an approximately 500 by 500-metre pixel area that being potentially heterogeneous – the spatial coverage/existence or share of the given feature within the pixel area. In order to validate the percentage values, we needed to know the real share or existence of the DPDH within the cell. Therefore, a new validation dataset has been collected and developed. Four datasets are planned for the Visegrád Countries (Czech Republic, Hungary, Poland and Slovakia) using the same procedure.

The validation was based on randomly selected validation sites. These sites were moved to the pixel centre, where a profile was excavated, described and all observed DPDH were recorded. Four additional auger holes were deepened at 100 m distance to the North, East, South and West directions from the opened profile. These auger holes were described in the same way and DPDHs were recorded as well. In the end, each validation site had five observations within the pixel, and existence percentages of 20, 40, 60, 80 or 100 could be calculated as the likelihood of occurrence within the pixel. These numbers can be used to characterise the homogeneity of the pixel and to validate the results of the probability classification. The validation was done for the RSG and texture data of the area of Hungary, the distribution of the validation sites is shown in *Figure 5.*

Results and discussion

Any DSM exercise and model development requires a deep understanding of the soil resources and the soil forming environment of the target area. Therefore, the first step in this study was the definition of the potential soil classes that occur within the area. The workflow of this step follows the original SOTER framework. It starts with the stratification of the landscape into homogeneous units defined by physiography and parent material. These

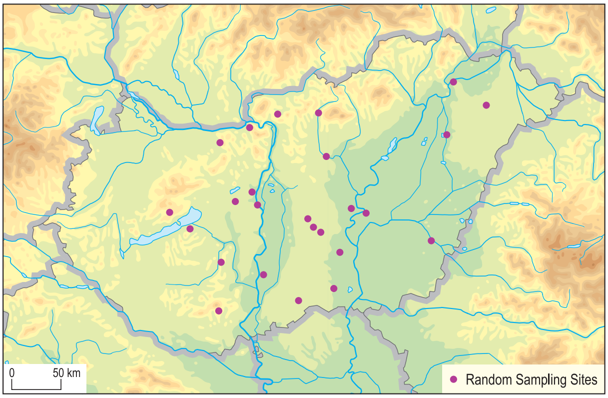

Fig. 5. The randomly selected validation sites around Hungary

two maps were combined to create the final stratification for the area (see *Figure 3*). The texture of the unconsolidated sediments on the plains has a strong correlation with the origin of the parent material in Central Europe. Clayey materials of the plains always have an alluvial origin and occur in the lower lying floodplains. The loam class refers to the deposited in situ or transported loess with a little bit higher elevation and still relatively low relief, while the sands are alluvial and later reworked by the wind. The first two classes often have low relief, while the dune formation of the sand regions results in stronger relief. That is why relief intensity, potential drainage density (PDD) (Dobos, E. and Daroussin, J. 2007) and the groundwater level layers had a significant contribution to the separation of these classes (Dobos, E. *et al.* 2013b).

Any kind of existing texture map can be integrated into the process. However, due to the lack of high resolution, consistence texture datasets, we used LUCAS data within a DSM procedure to derive the texture layer. The LUCAS – combined with the Hungarian, Czech and Romanian monitoring point datasets – has been reclassified into three texture classes, namely sand, loam, and clay, and a maximum likelihood classification using the integrated MODIS/SRTM dataset was performed. The overall class performance calculated with the leave-one-out method was 45.5 per cent with 22.8 per cent Kappa value. The visual check indicated a strong over-classification of the clay class over the loam. Therefore, additional loam areas were identified from different soil maps and added to the training dataset to refine the results. With the addition of the new training data, the overall class performance was increased to 88.7 per cent (with 26.1% Kappa), but the strong over-classification of the clay class was still evident.

These classes make a real and significant difference between the soil forming processes of the plain areas and separates the different soil associations. Therefore, the texture was used to refine the stratification of the plain areas and divide them into two subclasses of fine and coarse textured parent material. The soils of the sand and gravelly-sand regions are different from the ones forming on loamy or clayey material. Further differentiation within the fine texture class to loam and clay classes would have been advantageous, but the input texture image did not make a good separation between these classes. Areas having clay-loam texture – prevalent on the alluvial area of the Great Hungarian Plain – were classified as clay. Therefore, clayey soils – and thus the Vertisols – are artificially overrepresented in the target area. Fortunately, the separation between the fine and coarse textured areas is much more reliable and makes a good input for further classification (see *Figure 4*).

Stratification was followed by the definition of soil associations, the existing WRB reference soil groups for each stratification classes. The list of WRB reference soil groups is given in the last column of *Figure 6*. A minimum set of WRB DPDH was defined that is needed to classify the RSG classes – lines 5–16 in *Table 1*. By using the DPDH set and the stratification classes, a simplified classification tree was developed to classify each pixel according to its most likely RSG class *(Figure 6).*

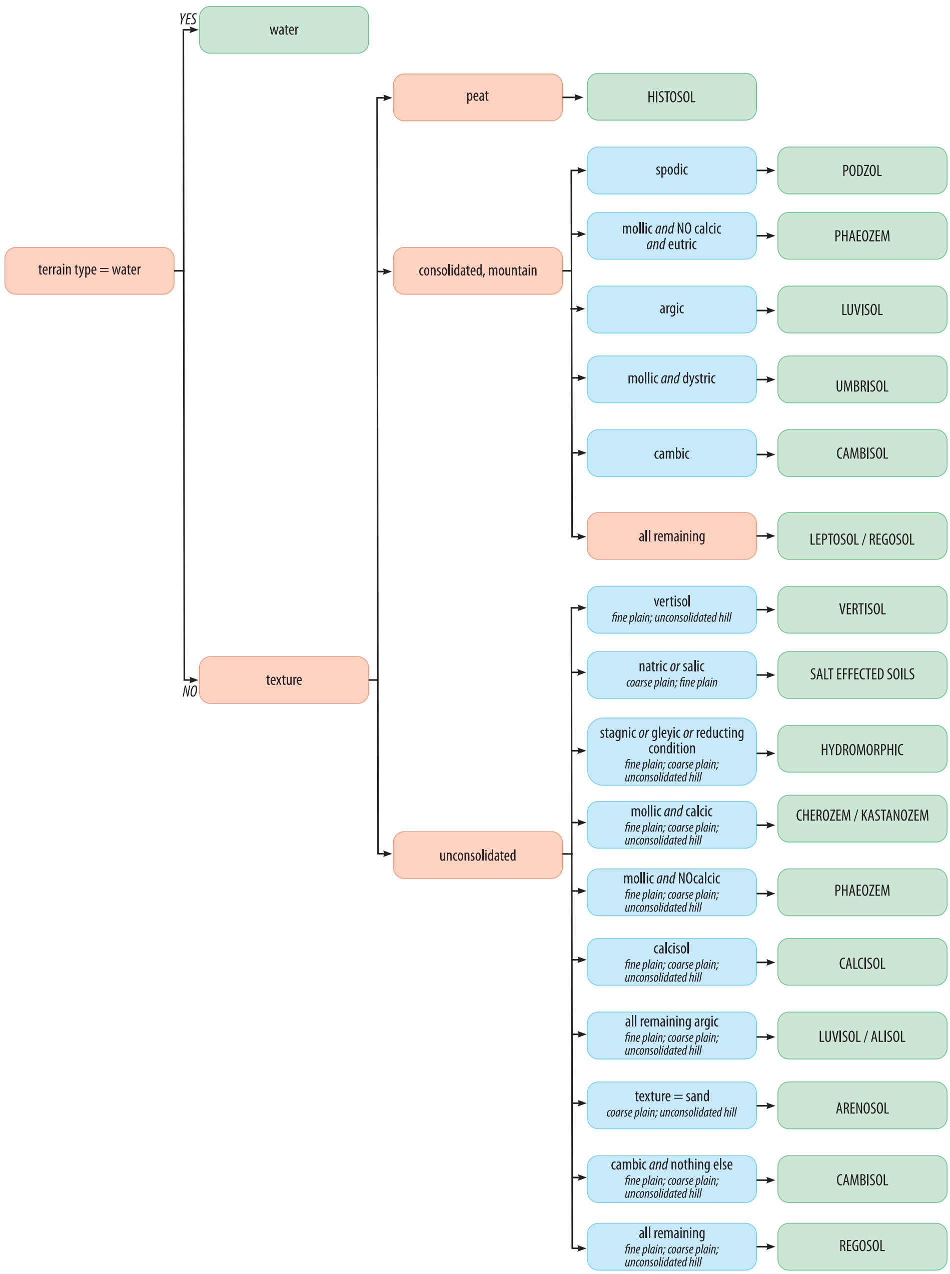

Fig. 6. Simplified classification tree for the WRB RSGs

An ArcGIS module containing the nested conditional function system was developed and made available to the public. This module requires an input gridstack with a predefined structure and standardised layers of DPDH (see *Table 1*). The input layers of the

Table 2. The validation results for the Hungarian territory of the image

Nr.	Classification category		Texture class	
	Field observation	Estimated	Field observation	Estimated
1	Lamellic Arenosol	Regosol	sand	clay
2	Calcic Chernozem	Vertisol	silt	clay
3	Calcic, Endogleyic Chernozem (pachic, siltic)	Vertisol	silt	clay
4	Calcic Chernozem (pachic, siltic)	Vertisol	silty clay	clay
5	Endocalcic, Vertic Chernozem (pachic, epiruptic, episiltic)	Vertisol	loamy clay	clay
6	Calcaric Arenosol	Arenosol	sand	sand
7	Calcic Chernozem	Vertisol	loamy clay	clay
8	Calcaric Arenosol	Arenosol	sand	sand
9	Calcic Endogleyic Chernozem	Chernozem	silt loam	clay
10	Endogleyic Regosol (calcaric)	Hidromorphic	loamy clay	clay
11	Pheozem/Kastanozem	Chernozem	silt loam	loam
12	Kastanozem/Chernozem	Regosol	loamy clay	loam
13	Leptosol	Luvisol	clay	loam
14	Chernozem/Gleysol	Histosol	silt	peat
15	Haplic Calcisol (siltic)	Luvisol	silt	consolidated
16	Luvic Phaeozem (clayic)	Luvisol	clay	consolidated
17	Endogleyic, Cutanic, Luvisol (siltic)	Luvisol/Alisol	loam	loam
18	Calcic Chernozem (pachic)	Chernozem	sandy loam	clay
19	Chernozem	Chernozem	silt loam	loam
20	Chernozem	Chernozem	loam	loam
21	Chernozem/Calcisol	Regosol	loamy sand	clay
22	Regosol	Regosol	loam	loam

gridstack are developed with a standard RS classification procedure using the MODIS/SRTM image described in the 2.3. section of the methods part of the paper. This probability classification approach is based on the signature file/training dataset, which was developed from legacy data using several transformations, translation and correlation algorithms and expert knowledge. Examples of these images are given in *Figure 7.*

Figure 8 shows the final product of the classification, having the WRB RSG classes assigned to each of the pixels. Only the Hungarian part of the window is described here in detail, because the rest of the image has not been validated by unbiased data. However, the general trends of soil class distribution are also recognisable and matches with the legacy soil maps.

A group of experts has interpreted the Hungarian part of the image. This image corresponds well with the known picture of the soil class distribution of the area. There were two major comments on the content. The first one is the overestimation of the Vertisol area, which was due to the texture map. It was stated earlier that the areas having clay-loam texture, the most dominant texture of the alluvial areas of the Hungarian plain, was classified mainly to the clay class. That has increased the potential area of Vertisol occurrence and resulted in some misclassification between the fine textured Chernozems

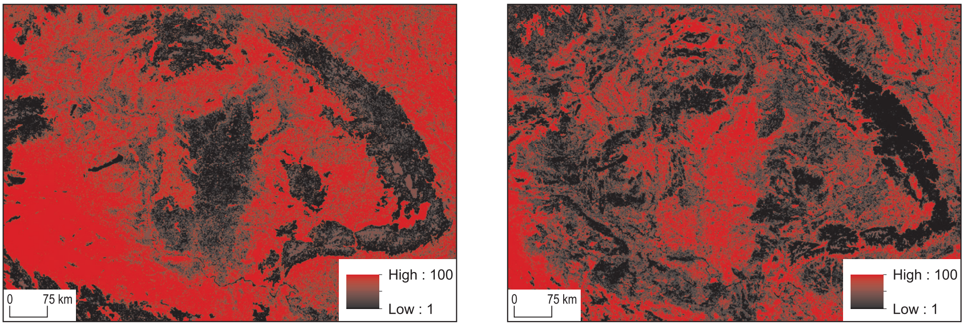

Fig. 7. Examples of the probability layers for the WRB Argic and the Mollic horizons

and the Vertisols. However, even the field differentiation between the two classes is often difficult and makes the training data sometimes unreliable. Especially, because the Hungarian soil classification system does not recognise Vertisols as a separate class, and no diagnostic criteria had been collected at the field for identifying the vertic properties, thus no related input data is available. As there is no one to one correlation between any Hungarian soil classification unit (soil type) and the WRB Vertisols, this information was extracted indirectly from related properties, like clay content, which is not always satisfactory and significant uncertainty may have been introduced this way.

The second comment was on the Calcisols. It was very interesting to see the Calcisol RSG on the Hungarian soil map. A Calcic horizon has three basic criteria to meet, 15 per cent or more total $CaCO_3$, has at least 5 per cent secondary carbonate and has a minimum thickness of 15 cm. There are large sandy and loess areas in Hungary, where huge amount of primary carbonates – over 15–20 per cent – are present in the parent material. This carbonate is partly leached entirely from the upper horizons and accumulated in the deeper horizons as accumulated secondary carbonate. In case of sand having no any significant diagnostic horizon other than the calcic, the soil keys out as Haplic Calcisol (Arenic) according to WRB classification, which is quite a common situation in the Danube–Tisza Interfluve area. A similar situation may occur on loess, where the calcic horizon is formed under a mollic that may have been eroded away due to intensive agriculture and high relief resulting in a Haplic Calcisol (Siltic). These two kinds of conditions are quite common and represent significantly large areas of Hungary, but it has not been recognised in the Hungarian classification yet, and these soils were classified as Arenosols or Regosols.

The concept of Calcisols has been developed for the semiarid regions with strong evaporation and $CaCO_3$ accumulation from the $CaCO_3$ rich groundwater, but diagnostics based classification systems describe the current features and soil genetics has only secondary importance. Not following the diagnostic rules may result in a definite inconsistency in any of these datasets. Subjectivity, or having a preconception in soil classification or correlation process is quite a common problem and is difficult to overcome. One of the main advantages of this approach is the objectivity of the classification rule.

In order to validate the results, the Validat. DSM dataset was used (Dobos, E. *et al.* 2013a, 2014). There were 23 randomly selected validation sites in Hungary distributed all over the country (see *Figure 5*). Each site had five observations, one profile and four auger holes. This procedure was developed to handle the within-pixel heterogeneity of the soils. *Table 2.* shows the comparison results on the RSG and the texture classes.

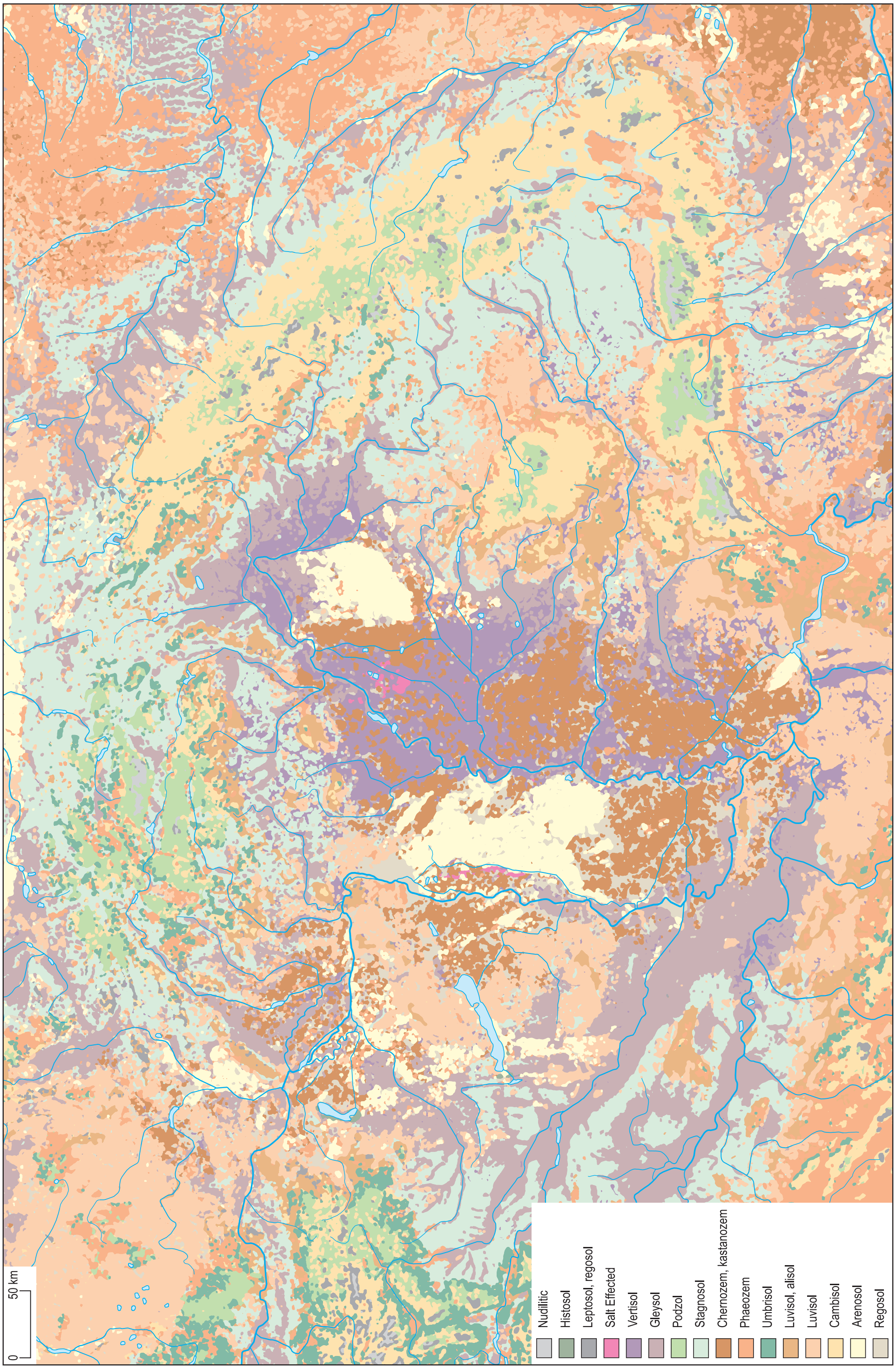

Fig. 8. The output image of the WRB RSG classification modul

Observations 2, 3, 4, 5 and 7 represent the Chernozem/Vertisol problem, that has been identified by the experts as well. These five observations represent the same genetic area and are located in the valleys of the Tisza and Körös rivers, where the silt-loam and clay-loam textured alluvial sediments are the dominant ones, but were partly misclassified as clayey textured soils and as a consequence of this to be Vertisols. Arenosols, Chernozems and Luvisols are mainly classified well. Even in the case of a few misclassifications, the diagnostic feature of the estimated DPDH is partly there, like the argic for the Luvisols, or gleyic, endogleyic for the Hydromorphic soil types (combined class of Gleysols and Stagnosols). A similar trend is evident, in the texture class comparisons as well, the majority of the misclassified classes are located in the Vertisol/Chernozem problem area.

Conclusions

Traditional soil maps are no longer able to present our knowledge on soils in a format that matches the need of interdisciplinary users, have the thematic and spatial resolution comparable with other digital data sources or that fits into a GIS-based modelling environment. Soil Database developers focus more on the property based maps with measured or more commonly estimated values, than on the soil classification category-based ones. These category maps require soil expert knowledge to interpret their content and translate them to specific properties and processes.

There are several important, commonly used properties, which are very difficult to measure and are usually derived from soil classes using pedotransfer formulas. The efficiency and uncertainty depends largely on the input data quality and resolution. This situation is not likely to change in the near future, soil science and its knowledge on soil genesis and processes expressed in the classification categories is still needed for soil data development. A new generation of soil maps that meet the requirements of data users and present our qualitative knowledge on the soil processes, like this RSG map, is needed.

This paper presented a novel way of soil information and soil database development using legacy data and DSM tools. The output is a multi-layer dataset containing several important WRB diagnostic features, reference soil groups, horizons and properties in raster format, capable of modelling the spatial continuum of the complex soil processes and features. These features alone represent complex properties of the soils, which can be easily linked to soil management and soil function related problems, and can be integrated into any specific model, where complex soil classification categories were inappropriate. The SRTM and MODIS supported development of these layers make use of the high spatial resolution of these covariates describing the variability of the soil forming environment in high detail.

It was concluded, that these images have a lot more detail than any of the previous, national scale maps. Despite its rough thematic resolution – only RSG without any prefix or suffix qualifiers is given – it shows the soil regions and soil associations clearly and also the transitions between them. A huge amount of spatial detail was introduced by the SRTM and MODIS data, which makes this dataset more applicable, even at a regional level. This spatial detail is further strengthened by the additional DPDH layers, which are ready to serve specific requirements without any intermediate interpretation need.

The original database idea and structure follows the SOTER approach, and in its sense, it can be correlated with several legacy datasets, but at the same time, a lot of extra knowledge, spatial details were integrated through the introduction of the high resolution digital data sources, like digital elevation data, or satellite images. While the resulted structure is similar to the legacy datasets, the development procedure is novel. Then legacy datasets were developed by compiling and harmonising soil maps having already generalised information. The traditional harmonisation procedure is often based on only rough estimations and correlation algorithms due to the lack of detailed, specific soil information. This procedure leaves off the use of existing map geometrics and applies point and specific soil property data based DSM tools and approaches. The input variables include the commonly accepted terrain and parent material features agreed on by the traditional soil science community, but in a high resolution, quantitative environment. Besides the resulting soil datasets and attribute data, the most important value of this dataset is the regionalization, the derived spatial patterns defined by the soil forming factors – described by the input datasets. The integration of any of these images into a quantitative data estimation algorithm as the pre-stratification image may significantly improve the model performance. The integration of one RSG layer can replace several covariates that describe the soil forming environment.

The model performance and accuracy are difficult to measure, but the general performance is always the function of the quality and quantity of input calibration, training datasets and the expert knowledge of the modellers. The Hungarian window shows the highest detail, due to the highest amount of data and understanding of the local soil resources. Subjectivity is still involved in a certain sense because some of the datasets are based on field morphology, which is impossible to overcome.

Besides, one of the major improvements has been the application of the updated standards for soil descriptions and soil classification. The master horizon designation, subordinate characteristics and site descriptions follow the 2006 edition of the FAO Guidelines for soil description (FAO, 2006). The classification of soils and the related diagnostic horizons, properties and materials are described and coded according to the World Reference Base for soil recourses (IUSS Working Group WRB, 2007a, b). The new soil map of the Carpathian Basin – where several soil datasets of the different countries occupying the area have to be harmonised – has applied this methodology to produce the soil map of the region (Pásztor, L. *et al.* 2018).

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The potential of regulating ecosystem service – filtering potential for inorganic pollutants – supplied by soils of Slovakia

Jarmila MAKOVNÍKOVÁ[1], Boris PÁLKA[1], Miloš ŠIRÁŇ[2], Miroslava KIZEKOVÁ[2] and Radoslava KANIANSKA[3]

Abstract

The concept of agroecosystem services combines environmental and socio-economic approaches to the analysis and evaluation of natural capital. A multi-criteria approach to spatial quantification of ecosystem services allows explicit assessment of the potential of agroecosystems to provide agroecosystem services and to adapt the land management under regional conditions. For the spatial quantifying of agroecosystem services potential of agricultural land in Slovakia, we have created a mapping unit by combining four input layers (climatic region, slope topography, soil texture and land use). In ecosystems of agricultural land, regulation of water regime, control of soil erosion, climate regulation and soil filtration are the main regulating services. Filtering potential was calculated as accumulative function of soil sorption potential and potential of total content of inorganic pollutants evaluated according to The Slovak Soil Law. Calculated potential was categorised into five categories (very low, low, medium, high and very high). The distribution of the filtering potential using spatial mapping units show that in Slovakia more than 41 per cent of agroecosystems have very high filtering potential (for inorganic pollutants), mostly in the Bratislava, Nitra and Trnava regions. Ecosystems with low potential (more than 41 per cent of agricultural land) are predominantly located on Fluvisols (along Váh, Hron and Bodrog rivers) with a higher content of risk elements in alluvial sediments (caused by anthropogenic deposition). The mountain soils on grassland are also strongly involved in very low category of filtering potential, predominantly in the Banská Bystrica, Žilina and Prešov regions. The greatest differences among regions was found in relation to climatic conditions, land use and the diversity of soil types.

Keywords: ecosystem services, soil pollutants, filtering potential, Slovakia, district, region

Introduction

Ecosystem services are the benefits that natural capital provides to society. Ecosystem services represent an interaction between ecological and social systems as only those ecosystem processes that contribute to the fulfilment of human needs are defined as ecosystem services (Birghofer, K. *et al*. 2015). According to Costanza, R. *et al*. (2017) the connections between ecosystem processes, functions and benefits to humankind are non-linear and dynamic. Dominati, E.J. *et al*. (2010) divided ecosystem services linked to natural capital into three main categories (provisioning, regulating and cultural). The concept of ecosystem services represents a bridge between ecological and economical approaches and helps to create a transdisciplinary ecological economy (Haines-Young, R. *et al*. 2012). This concept brings a new comprehensive view on the issue of effective use of natural goods not only from

[1] National Agricultural and Food Centre/ Soil Science and Conservation Research Institute Bratislava, Regional Station Banská Bystrica, Mládežnícka 36, 974 04 Banská Bystrica, Slovakia. Correspondent author's e-mail: j.makovnikova@nppc.sk

[2] National Agricultural and Food Centre / Grassland and Mountain Agriculture Research Institute, Mládežnícka 36, 974 04 Banská Bystrica, Slovakia.

[3] Department of Environment, Faculty of Natural Sciences, Matej Bel University Národná 12, 974 01 Banská Bystrica, Slovakia.

the point of view of production but additionally from the point of view of all services provided by ecosystems. The concept of ecosystem services can be included in land use planning and decision support tools (Burghard, B. and Maes, J. 2017; Spake, R. *et al.* 2017).

Agricultural systems are intensely managed, controlled and regulated by humans (Dominati, E.J. *et al*. 2010). We consider the agroecosystem not only as a means of production but also as a part of the natural environment, where the pedosphere is multifunctional in terms of its processes, functions and services (MEA 2005; Burghard, B. *et al.* 2014; Coyle, C. *et al.* 2016). Agroecosystems, such as arable land and grassland, are mostly biotopes for only a few plant and animal species and are very poor in terms of biodiversity because of the targeted cultivation of monocultures. On the other hand, agricultural land significantly contributes to the fulfilment of regulating services (potential of water regime regulation filtration potential). Rodríguez, J.P. *et al*. (2006) noticed that when regulating services are providing they are more likely to be taken for granted and therefore less attention is paid to their evaluation in agroecosystems. According to Burghard, B. *et al.* (2014) we consider ecosystem services potential (capacity) as the hypothetical maximum yield of ecosystem services.

Regulating services are benefits created by the self-sustaining capabilities of ecosystems, the regulation of ecosystem processes. All these services are not directly consumed by man as goods, but regulating services do bring many direct benefits by keeping safe and habitable environments, supporting food production systems or processing and removing waste and pollution (Burghard, B. and Maes, J. 2017). In ecosystems of the agricultural land, regulation of water regime, control of soil erosion, climate regulation and soil filtration of pollutants are the main regulating services (Dominati, E.J. 2013). The filtering capacity of soil refers to its ability to retain nutrients and contaminants bonding them with varying intensity (from weak to strong) to organic or mineral soil constituents, and thereby preventing their release into water passing through the soil profile (Burghard, B. and Maes, J. 2017). Inappropriate land management can lead to land degradation and thus can reduce the provision of agroecosystem services (Dendoncker, N. *et al*. 2018). However, in the present widespread scenario of multiple problems including land degradation and land pollution, there is a need to address regulating services, including soil filtration, in an objective manner.

Techniques that are often used to evaluate and map ecosystem services are expert-based estimations, expert-scoring, through land use classes and land use cover (Burkhard, B. *et al*. 2009) or participatory GIS mapping (Maes, J. *et al*. 2018). The concept of natural capital and agroecosystem services are widely accepted and their potential contribution to better environmental management is also acknowledged (MEA 2005). However, their practical applications such as distribution and mapping are still insufficient and limited. Biophysical indicators (soil quality indicators) as well as localization and changes over space and time due to human induced land cover and land use are used by many authors to evaluate ecosystem services (Dominati, E.J. *et al*. 2010; Alam, M. *et al*. 2016). The quantification and mapping of ecosystem services distribution is also considered one of the main requirements for the implementation of the concept of ecosystem services into institutional decision-making.

The aim of this study was to evaluate and map regulating agroecosystem service (filtration potential for inorganic pollutants) in regions and districts of Slovak Republic.

Material and method

Filtering potential for soil pollutants depends on actual soil contamination and the potential of soil sorbents that are sensitive to the sorption of risk elements. Higher amounts of potential risk elements in the soils takes up the potential sorbent places and consequently reduces the overall soil potential for the sorption of the risk elements.

Filtering potential was calculated as accumulative function:

$$FP = SP + K, \quad (1)$$

where *FP* = filtering potential; *SP* = sorption potential of soil, *K* = potential of total content of inorganic contaminants evaluated according to The Slovak Law 220/2004 Z.

The evaluation of sorption potential of soil (*SP*) was calculated as a sum of quality factors (pH, Q_4^6) and quantity factors (Cox, H-depth of humus horizon) according to function:

$$SP = F(\text{pH}) + F(Q_4^6) + F(\text{Cox}) \cdot F(\text{H}) \quad (2)$$

Values were categorised into five categories as follows: 1 – very low relevant capacity (more than 6.50 points), category 2 – low relevant capacity (5.51–6.50 points), category 3 – medium relevant capacity (4.51–5.50 points), category 4 – high relevant capacity (3.50–4.50 points), category 5 – very high relevant capacity (lower than 3.50 points). The method is described in detail in our previous article Makovníková, J. *et al*. (2007).

Mapping units

Forouzangohar, M. *et al.* (2014) concluded that one of the best sampling and mapping strategies would be a regular grid scheme. For spatial quantification of regulating agroecosystem services of agricultural land in Slovakia, we have created a mapping unit by combining four input layers:

1. Climatic region (categories: moderately cold, moderately warm, warm and very warm);
2. Slope topography (categories: 0.0°–2.0°, 2.1°–5.0°, 5.1°–12.0°, and over 12.0°);
3. Soil texture (categories: soil particles < 0,01 mm less than 20%, 20–45%, and over 45%);
4. Land use (arable land, grassland and other cultures like sets, vineyards, hops).

Each mapping unit represents one cell of 100 m resolution in regular grid derived from EEA reference grid. Mapping units are compatible with the spatial units in international database (Corine Land Cover). We calculated a weighted average of the filtration potential for each mapping unit. Software package of the geographic information system ArcGIS® was used for processing the input geo-referenced digital data and the resulting maps.

For each region and district we calculated a weighted average of individual categories (of all grids that belong to a particular region or district) of filtering potential. The weighted average, in contrast to the average, takes into account the spatial distribution (area representation) of each category. Software package of the geographic information system ArcGIS® was used for processing the input geo-referenced digital data and the resulting maps. Moreover, the methodology developed in this paper is replicable and can be applied by planners if they are proficient in geographic information systems.

Data sources

Available data sources for the categorization and mapping consisted of primary (spatial information on the soil bodies) and secondary (data of relevant soil properties) geo-referenced data. Data from the Geochemical Atlas of Soils of Slovakia, data from the Digital Soil Map of Slovakia and data of Soil Monitoring of Slovakia were used to evaluate the potential of total content of inorganic contaminants in soil and sorption potential of soil. The basis for generating mapping units were a classification of agro-climatic regions provided by the Information Service of the National Agricultural and Food Centre/Soil Science and Conservation Research Institute (NAFC-SSCRI, 2015), Land Parcel Identification System (LPIS) and Digital Soil Map of Slovakia.

Results and discussion

A multi-criteria approach to the spatial quantification of ecosystem services related to socio-economic indicators allows the explicit assessment of the potential of ecosystems of agricultural land to provide agroecosystem services. The proposed mapping system connects ecosystem service with landscape coverage. This is one of the conditions for using this model to monitor changes in land use management, spatial planning, and implementation of the assessment of the potential of natural capital services in socio-economic planning within the region and landscape. The distribution of the filtering potential using spatial mapping units is shown in *Figure 1.* In Slovakia 41.67 per cent of agroecosystems have very high filtering potential for inorganic pollutants.

Very high filtering potential is typical for ecosystems of arable land developed on loess located in the Danube and the Eastern Slovak Lowland without any anthropogenic and geochemical deposition. According to Greiner, L. *et al*. (2017) soil properties and soil functions are critical to ensure the provision of ecosystem services. These ecosystems located on Chernozems and Cutanic Luvisols, on soils characterized by high carbonate content with a neutral or slightly alkaline pH value (Kobza, J. *et al*. 2014) and with high organic matter content, have the highest filtering potential. In Slovakia ecosystems of arable land of low filtering potential (41.12% of the area) are predominantly located on Fluvisols (along Váh, Hron and Bodrog rivers). The low filtering potential of these ecosystems is due by a higher content of risk elements in alluvial sediments (anthropogenic deposition) in combination with the low potential of soil sorbents (Makovniková, J. 2001; Donisa, C. *et al*. 2003; Boruvka, L. and Drabek, O. 2004; Makovniková, J. *et al*. 2007; Makovniková, J. and Barančíková, G. 2009).

The mountain soils on grassland (Podzols, Dystric Cambisols located south-west and east of Banská Bystrica, east of Spišská Nová Ves, and in the mountain regions of Western Carpathians) are also strongly involved in the very low category of filtering potential. These soils are developed on substrates with higher content of risk elements due predominantly to parent material (geochemical anomalies) (Čurlík, J. 2011). Permanent grasslands are mostly at higher altitudes as well as on higher slopes, on soils with low sorption potential developed on substrates with higher content of risk elements (Makovniková, J. *et al*. 2007; Kobza, J. *et al.* 2014). Most of the ecosystems of agricultural land with high potential for provisioning services belong to a category with very high or high filtering potential.

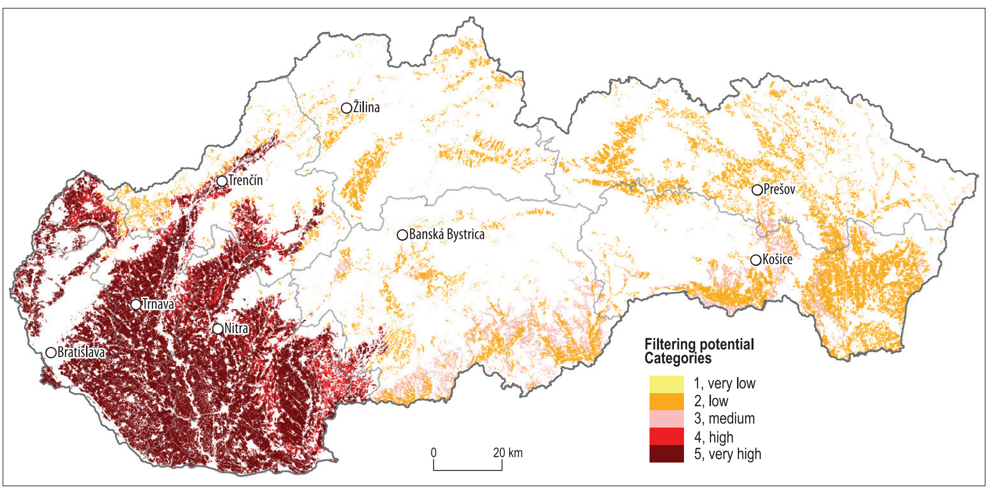

Fig. 1. The filtering potential of agroecosystems in Slovakia (edited by Makovníková, J. and Pálka, B.)

This proposed mapping system was used to assess agroecosystem service, filtering potential, in the regions of the Slovak Republic. There are currently eight regions of Slovakia and they correspond to the EU's NUTS 3 level of local administrative units. Each region consists of districts (there are currently 79 districts).

The distribution of the filtering potential using spatial mapping units in regions of Slovakia is illustrated in *Figure 2*. The variability within individual categories (minimum and maximum value) is shown in *Table 1*.

The distribution of the filtering potential using spatial mapping units in districts of Slovakia is illustrated in *Figure 3*.

In the *Bratislava region* more than 90 per cent of the total area of used agricultural land belongs to the category with a very high filtering potential for inorganic soil pollutants (see *Figure 2* and *3*). Only a small share of categories of high and moderate potential of this service can be found in this region.

In each district of the *Nitra region*, the category of very high filtering potential of soil pollutants varies from 71.40 per cent to 99.32 per cent (see *Table 1*) and category of high potential varies from 0.68 per cent to 21.69 per cent of the total area of used agricultural land. Only in three districts (Levice, Topoľčany and Nové Zámky districts) was determined a low

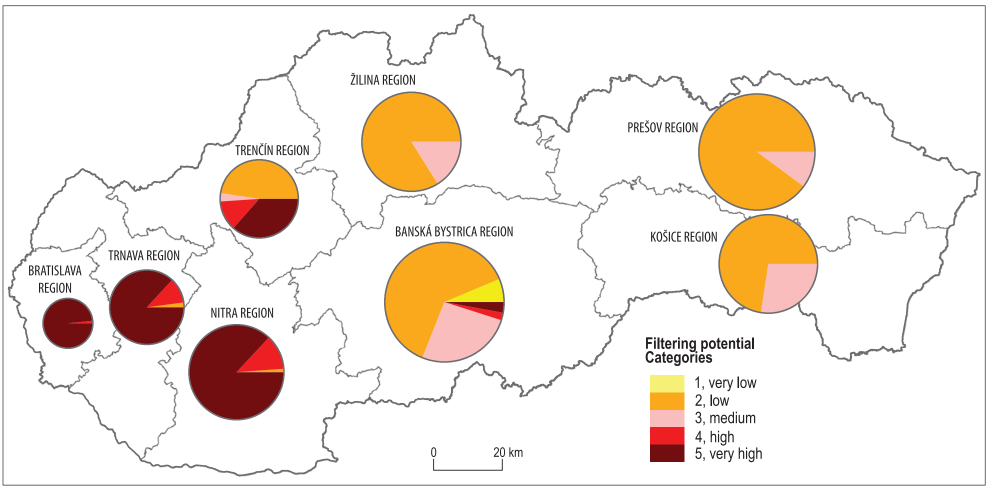

Fig. 2. The filtering potential for inorganic soil pollutants in regions of Slovakia (edited by Makovníková, J. and Pálka, B.)

Table 1. The variability (minimum-maximum) of filtering potential in regions

Region/NUTs3	Category of filtering potential in % of used agricultural land				
	Very low	Low	Medium	High	Very high
Bratislava/SK010	0.00–0.08	0.00–1.15	0.02–0.15	0.29–5.53	94.45–99.71
Nitra/SK023	0.00–0.00	0.48–6.31	0.00–0.60	0.68–21.69	71.40–99.32
Trenčín/SK022	0.01–1.30	1.61–93.29	0.16–6.69	0.00–29.46	3.05–68.77
Trnava/SK023	0.00–0.00	0.00–10.94	0.00–0.83	0.18–21.76	73.04–98.87
Banská Bystrica/SK032	0.00–30.22	37.54–96.79	2.21–53.35	4.24–22.07	7.54–29.53
Žilina/SK031	0.10–4.71	69.54–93.07	6.14–29.18	0.00–0.00	0.00–0.00
Prešov/SK041	0.08–3.09	82.03–95.93	2.58–17.42	0.00–0.00	0.00–0.00
Košice/SK042	0.00–2.56	12.32–94.56	4.46–87.68	0.00–0.00	0.00–0.00

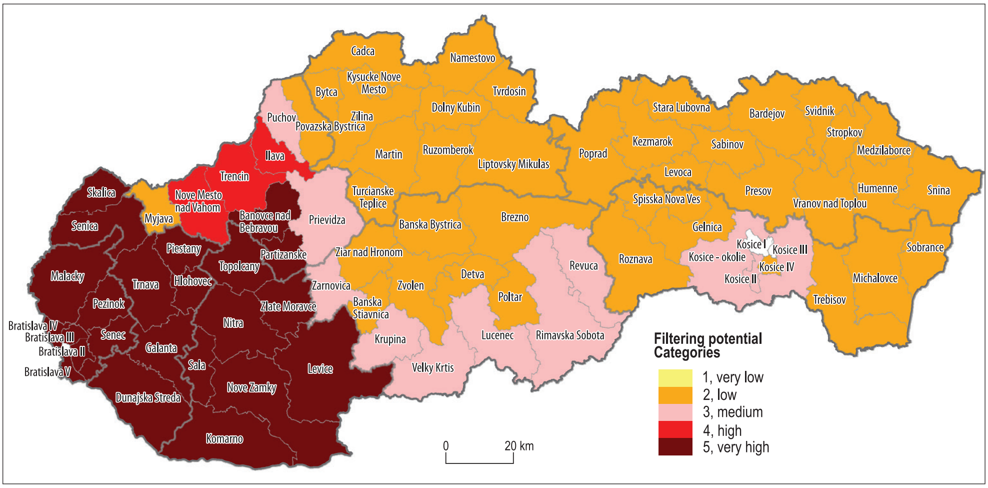

Fig. 3. The filtering potential for inorganic soil pollutants in districts of Slovakia (edited by Makovníková, J. and Pálka, B.)

category of filtering potential (from 0.48% to 6.31% of used agricultural land).

In the *Trenčín region* there is high variability among districts of this regulating service. In two districts (Myjava district and Považská Bystrica district) categories of low filtering potential are present in more than 80 per cent of the total area of used agricultural land. The share of the category of very high filtering potential ranges from 3.05 per cent (Myjava district) to 68.77 per cent (Partizánske district) of the total area of used agricultural land.

In the *Trnava region* share of the category of very high filtering potential ranges from 73.04 per cent (Senica district) to 98.87 per cent (Dunajská Streda district) and the category of high potential varies from 0.18 per cent (Dunajská Streda district) to 21.76 per cent (Skalica district) of the total area of used agricultural land. There is a small share of categories of low and moderate potential of this regulating service in four districts.

In the *Banská Bystrica region* there is a high category of low filtering potential for soil pollutants, in 3 districts (Banská Bystrica, Banská Štiavnica and Zvolen district) it is over 80 per cent and in eight districts more than 50 per cent of total area of used agricultural land. High and very high potential for this regulating service is found in two southern districts (Krupina and Žarnovica district).

A majority of the districts of the *Žilina region* have a high proportion of categories of moderate and low potential for soil filtration. A significant percentage of the category of low filtering potential (lower than 90%) is reported in seven districts from 13 districts in this region. Categories of high and very high potential are not represented in this region.

In the *Prešov region* the majority of districts have a high percentage area in the category of low filtering potential (ranges from 82.03% to 95.93%). There is an absence of the categories of very high and high potential for this regulating service in this region.

In the *Košice region* a significant percentage of the category of low filtering potential (more than 80%) is reported in three districts (Gelnica, Sobrance and Spišská Nová Ves district). The share of the category of medium filtering potential for soil pollutants ranges from 4.46 per cent (Gelnica district) to 87.68 per cent (Košice III district) of the total area of used agricultural land. Similar to Prešov and Žilina regions, categories of high and very high potential are not represented in this region.

Because the provision of ecosystem service depends on biophysical, land use and climate (Makovniková, J. *et al*. 2007; Burghard, B. *et al*. 2014), the distribution of this service is geographically different. The greatest differences among regions was found in relation to climatic conditions, land use type and diversity of soil types. According to Frélichová, J. and Fanta, J. (2015), the climate has an important impact on the distribution of agro-ecosystem services. In Slovakia there are very low and low categories of filtering potential characteristic of areas with a cold to moderately warm climate, higher slopes and a higher percentage of clay particles in soil texture. Very warm climatic region, low slopes and medium content of clay fraction are predominantly in areas with high and very high filtering potential. The climate and the substrate are among the major factors influencing the soil genesis. Climate also affects the management and land use. Land use types can have positive or negative impacts on the pedosphere multi-functionality in terms of its processes, functions and services (Dominati, E.J. *et al*. 2014). Intensive agricultural practices typically reduce soil organic matter content and negatively impact soil biodiversity, which are recognized as major drivers of the soil ecosystem process. The using of low quality inorganic fertilizers can increase anthropogenic soil load which negatively influence filtering potential (Makovniková, J. 2001).

Conclusions

In this study, the first assessment of one of the regulating agroecosystem services, soil filtration using spatial mapping units is applied. The evaluation of agroecosystem service linked to spatial visualization was used the assess the filtering potential in the regions of the Slovak Republic (using NUTS classification of regions of European Union countries NUTs 3). We conclude that this assessment and mapping allows us to link the analysis of natural capital, land use and filtering potential (one of the regulating agroecosystem services) in the regions and districts of the Slovak Republic. The spatial mapping of ecosystem service is useful for providing guidelines and limits for policy development on land management and land use changes at local and regional levels.

In Slovakia very high filtering potential (for inorganic pollutants) is present in more than 41 per cent of agroecosystems, mostly in the Bratislava, Nitra and Trnava regions. On the other hand, more than 41 per cent of the total agricultural land belong to the category with low filtering potential. Ecosystems with very low filtering potential (1.13% of the total agricultural land) are located at higher altitudes, steeper slopes, on soils with lower sorption potential as well as soils developed on substrates with higher content of risk elements, predominantly mountain soils. The greatest differences among regions ca be found in relation to climatic conditions, land use and diversity of soil types. The direct effect on filtering potential also has a degree of soil load due to anthropogenic or geochemical contamination.

It is important to note that agroecosystems are not able to provide ecosystem services without any intervention by humans (human and social capital). Inappropriate land management practices are negatively related to ecosystem condition and will result in ecosystem degradation that reduces the agroecosystem services provided (Dendoncker, N.F. *et al.* 2018). Appropriate land management can act to improve the capacity of natural capital to generate ecosystem services. However, increasing of primary and secondary production of agroecosystems must be managed with regard to the sustainability of the soil multi-functionality and the sustainability of potential of agroecosystem to provide ecosystem services in their integrity. The mapping of ecosystem services and their integration into regional decision making and the optimization of ecosystem services potential can contribute to the sustainable use of ecosystems.

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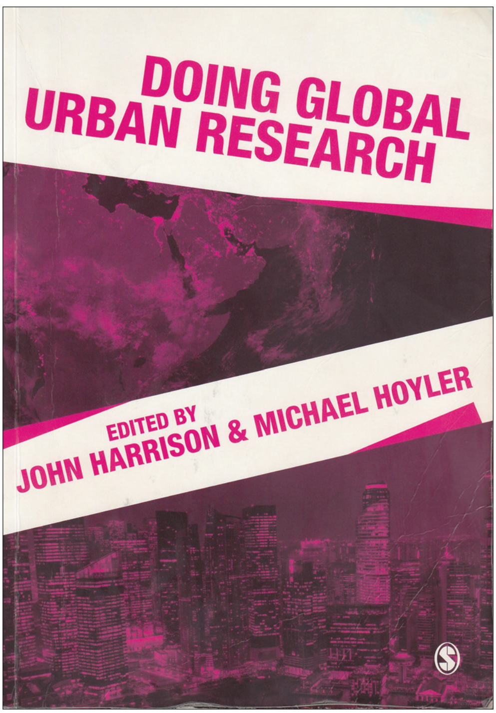
BOOK REVIEW SECTION

Harrison, J. and Hoyler, M. (eds.): Doing Global Urban Research. London–Thousand Oaks–New Delhi–Singapore, SAGE, 2018. 264 p

Urban world occupies a small percentage of the surface of the Earth but it is the area where the majority of the population and economic activities concentrate. According to "The New Urban Agenda" (UN Habitat, 2016), cities cover no more than 2 per cent of the total land area but host more than 54 per cent of population and contribute to around 70 per cent of the global GDP. At the same time, the urban world absorbs over 60 per cent of global energy resources and it generates more than 70 per cent of greenhouse gas emission and 70 per cent of global waste. It is no wonder, therefore, that urban research enjoys global interest. This popularity has led to the appearance of many related interdisciplinary publications, and nowadays it is extremely difficult to produce a book which contains original material and complements existing studies. Yet, John Harrison and Michael Hoyler as editors of the book have achieved this goal very well in my opinion.



The volume contains 16 chapters by both emerging and established scholars, which represent different disciplines and attitudes toward urban research. The level and depth of the content varies, but each part follows the same structure. Every chapter begins with an introduction outlining the authors' motivations. Section One helps then identify the key theories, ideas and concepts that are shaping this area of urban research. Section Two highlights some main challenges of contemporary research, both conceptual and practical. In Section Three, the authors focus on available analytical techniques. Section Four always provides a case study giving insight into research practice. Finally, Section Five contains individual reflections from each author on their experience of doing global urban studies. I find the adoption of this structure in every chapter a good idea, because it makes easy to find the links between various parts of the book, even if they discuss different topics.

The editors of the book provide an introduction in the first chapter *(Making Sense of the Global Urban)*. They define the goals and main research questions of the volume and identify the most popular research topics in contemporary urban studies. As they underline, the main inspiration for writing this book were questions from students about how to conduct research on urbanisation around the globe. It turned out that the answer is not easy at all and there is not a single right solution. Hence, they decided to examine more deeply planetary urbanisation, planetary suburbanisation and mega-regions. They found that new theories and concepts on global urban research have developed at far faster pace than empirical tools and analytical techniques. Besides, there is a relative lack of works that give insight into the opportunities and challenges, tools, techniques and theories of global urban research. This book was created as an answer for the aforementioned needs.

The second chapter by Nikos Katsikis discusses possible ways of *Visualizing the Planetary Urban*. The author stresses that is very difficult to grasp the complexity of urbanisation, as long as it is based on, and constrained by, a particular conceptualisation of the urban world (e.g. morphology based approaches to urban agglomerations, such as cities, metropolises etc., which primarily focus on socio-spatial configuration [growth, expansion, economic and demographic performance] and their mutual relationship [networks, polycentric urban regions]). This paradoxically leads, according to the author, to that the importance of relations between cities is widely recognised but poorly understood, and too much attention is paid to the 'unproductive binarism' (p. 13) of 'urban' and 'rural' worlds. The most important challenge is that researchers too often concentrate on a kind of 'meta-geography'(p. 15–16), the conceptual pre-assumption that the urban can and should be delineated spatially. Katsikis aptly underlines that the effort to find spatial boundaries becomes especially elusive for diffusion, the emerging polycentric structure of cities, and densification of infrastructural systems. The author also presents a few interesting examples of visualisation. I consider a promising idea to use density gradients to delineate urban areas, which one can determine by using a combination of particular thresholds developed from census statistics and remote sensing data. Unfortunately, maps, which add a lot to the text, are printed black and white, and in my view some parts of them are not fully readable.

The third chapter *Exploring the World City Network* by Peter J. Taylor and Ben Derudder relates to the internationally well-known research project conducted within the 'Globalisation and World Cities Group' (GaWC). Despite the large number of studies employing this approach, I read the chapter with great interest, especially the part about challenges and techniques of research. The chapter presents the subject in a comprehensive way, so I also recommend it to students who are interested in doing world network research.

Chapter 4 *(Analysing Cities and Networks)* by Zachary P. Neal also deals with city networks but, unlike in the previous chapter, its author more concentrates on relationships than attributes. Neal analyses city networks from the perspective of urban transportation networks, and he is particularly interested in how airline transportation links cities to national and global networks. Although this study may not seem to be a novel one at first sight, the author provides very strong arguments for the approach he presents, and he well illustrates its challenges and opportunities.

Chapter 5 *(Examining Global Urban Policy Mobilities)* by Cristina Temenos and Kevin Ward differs significantly from the previous chapters as it concentrates on policy mobilities. It discusses two interrelated and overlapping notions. The one focuses on the mobility of policy and associated expertise and knowledge, whereas the second one concentrates on the actors and practices through which policy is rendered mobile and is travelling. The authors highlight four elements of urban policy mobility, which are related to the mobilisation of knowledge, people, materials and politics, and require different research techniques. As a case study, the authors describe a unique project examining the role of transnational advocacy networks in mobilising an alternative policy model (focusing on activism and public health and drug policies) in cities across the Caribbean, Europe and North America. The main focus of the study is the link between globally operating and interconnected social movements and policy change along with their local implementation, which brings a new perspective to global urban research.

In Chapter 6 *(Tracking the Global Urbanists)*, Donald McNeill and Andrea Pollio are "tackling the apparently monolithic power of the global firm" (p. 81). Their approach might be surprising for regarding technology firms as urbanists. Typically, this term is applied to sectors with a direct interest in the creation of the built environment of cities, e.g. property developers, architects, engineers and urban designers. But the authors argue that one has to take into consideration much more actors today, including the economically most competitive ones, the software-driven firms. They focus on two companies, IBM and Uber, scrutinising them as global urbanists which are trying to influence urban policies and markets worldwide. I found noticeable the authors' survey about how apparently global actors 'landed' or got territorialised at different places, with different outcomes, and how they were acting experimentally and simultaneously, reviewing their centralised corporate strategies.

Chapters 7 and 8 address the very important concept of sustainable development. In Chapter 7 *(Engaging with Global Urban Governance)* Michele Acuto underlines the increasing global importance of urban policymakers, which is reflected by the rise of what he calls global urban governance. Acuto refers to the Habitat III Conference in October 2016 in Quito, Ecuador, which turned the global public attention to cities as places where a global agenda for sustainable development can start. Cities and networks, notably C40 Cities Climate Leadership Group (C40) and United Cities and Local Governance (UCLG), are on the front stage, with visible performances, commitments and interventions. They can be effective actors, taking part in the dynamics of global governance. In the next chapter on *Evaluating Global Urban Sustainability*, John Lauermann suggests that cities and perhaps only cities can save the planet from an environmental catastrophe. He concentrates on cities that act as 'urban laboratories', spaces for testing new technologies and design practices to change urban socio-technical systems. In the 'experimental city', urban development projects can be used as spaces for innovation. The author employs as case study some cities that hosted the Olympic Games, where experimental architecture, smart urban management and a variety of technologies for minimising the environmental footprint can be introduced.

Chapter 9 *(Scrutinizing Global Mega-Events)* by Christopher Gaffney, Sven Daniel Wolf and Martin

Müller describe how mega-events like the Olympic Games or the Football World Cup have become global urban forces. Mega-events meant for many cities which hosted them forced (and fast) reshaping of both urban politics and the built environment. I enjoyed that authors recognise mega-events as global urban phenomena, but also that they reveal why mega-events come along with as many contradictions as globalisation itself.

Chapters 10, 11 and 12 discuss topics like gentrification, right to the city, and suburbanisation, which are not associated at first glance with global urban research. Of course, gentrification and suburbanisation are global processes, but studies usually investigate them on the local level, not within a global urban research framework. Chapter 10 *(Studying Global Gentrification)* by Hyun Bang Shin is a strong manifesto emphasising that despite business-oriented approaches which try to depict gentrification as a positive urban process, it remains a phenomenon that highlights the looting and destruction of homes and neighbourhoods in order to promote the interests of the rich and powerful. Shin argues that gentrification research should have displacement along with its causes and consequences as its main focus, not only in the Global North, but also in the Global South.

David Wachsmuth takes a slightly different approach in Chapter 11 *(Researching the Global Right to the City)* along Henri Lefebvre's well known concept on "Right to the City" (Lefebvre, H. 1968). Wachsmuth stresses that the adjective 'global' can be used as a modifier of the right to the city. The concept is generally interpreted with regard to 'local' struggles over social reproduction and daily life. One has to understand the global right to the city, however, in the context of uneven spatial development: even 'global' processes take concrete forms in highly differentiated ways. The chapter provides a very interesting case study about the housing market in Vancouver, where the spectrum of 'right to the city' kind of housing claims ranges from the right to shelter to the right to property ownership and to the right to property investment.

In Chapter 12 *(Constructing Global Suburbia, One Critical Theory at a Time)* Roger Keil concentrates on worldwide processes that involve a large variety of phenomena from gated communities to suburban high-rise hubs with integral suburban ways of life.

Chapters 13, 14 and 15 emphasise the need for ethnographic, long-term and historical research within global urban research. In Chapter 13 *(Comparative Ethnographic Urban Research)* Tim Bunnell stresses the importance of ethnographical approaches in global urban research, for they can attach socio-cultural meanings and human experiences to the results of the burgeoning mix of research on urban studies. Kathrine V. Gough presents in Chapter 14 *(Doing Longitudinal Urban Research)* why research conducted over a longer time period has remarkable advantages over short-range projects, and how they can increase the explanatory power of empirical analysis. Gough takes an interesting case study of urban research in Pereira, Columbia, which very convincingly reveals the power of longitudinal studies.

Chapter 15 by Marina Dantas and Emma Hart *(Historical Approaches to Researching the Global Urban)* underline the significance of taking an historical approach in research. I fully agree with the authors that a more sophisticated understanding of human history helps produce novel research findings not only on empires and nations, but also on supra-national communities and networks formed by trade and intellectual exchanges. Historians recognise that the current process of globalisation has its own 'idiosyncrasies', mostly related to technological and financial development characteristic to the late twentieth and early twenty-first centuries. Nonetheless, they reject the assumption that we live in an exceptional era of global connectivity, and highlight patterns in past global contexts that are similar to certain global phenomena of the present day.

The last chapter *(Advancing Global Urban Research)* by the editors summarises the main findings of the book. It gives an overview of the most important research approaches presented in the book and reflections on them.

In fact, the authors of the volume barely make any direct reference to Central and Eastern Europe (for a few exceptions, see p. 44, for example). Still, this book can be really useful for Central and Eastern European researchers, especially if they are seeking inspiration to scrutinise urban complexity in an increasingly globalised world. Moreover, its studies are not only based on qualitative data, which are sometimes either not available or unreliable, but the authors use quantitative and mixed method approaches as well, which give more possibilities to integrate Central and Eastern Europe perspectives, and the predominant research approaches and methods in the region, into global urban research.

The volume is not an easy piece to review and as a reviewer I was a little disappointed at some points that the authors do not give me straight answers to the questions they put, so sometimes I felt confused and was wondering whether scholars are actually doing global urban research. However, after finishing reading the volume, I realised that I should not treat it as a 'normal academic textbook'. The aim of the authors is not to suggest a single viable solution or to give a definite answer to every question, but rather to share with us different approaches and also to stimulate further questions. Hence, this volume is a cohesive and conceptually rich interdisciplinary insight into the emerging field of global urban research.

It is a provocative guide about what has already been done and, which may be even more valuable, it also lets us better see what is possible in terms of scientific analysis. The book is a great reading for students and researchers who think about the urban, and research it, at the global scale. I recommend it especially to those who want to get inspiration and also to get involved in one of the many exciting research themes of global urban research.

Barbara Jaczewska[1]

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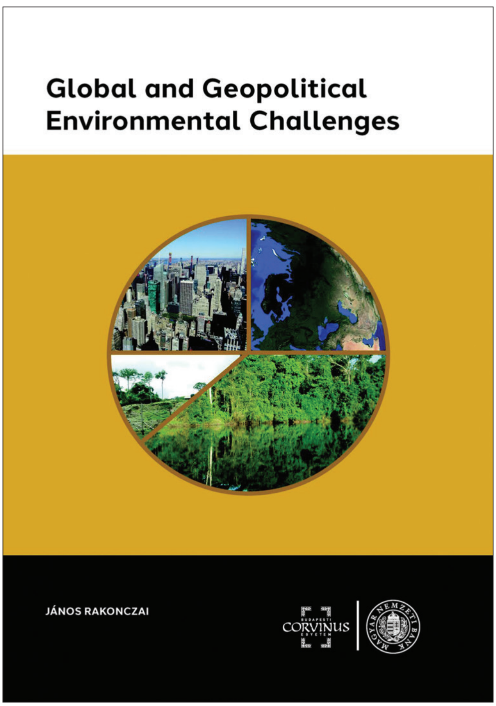
[1] Faculty of Geography and Regional Studies, University of Warsaw, Warsaw, Poland. E-mail: bgibki@uw.edu.pl

Rakonczai, J.: Global and Geopolitical Environmental Challenges. Budapest, Corvinus University of Budapest, 2018. 306 p.

Growing lifespans, increasing levels of consumption, and the apparently improving environmental conditions of developed and partly underdeveloped countries often make us forget about their environmental impacts, whereas the undoubtedly aggravating situation must turn our attention towards global problems. Recently, many people encounter obscure ideas about these crises, however, sooner or later, virtually everyone will be affected. Unsurprisingly, a multitude of books has been aiming to shed light on environmental challenges caused by the so-called 'explosion of globalisation' worldwide so far. Yet, the recent book differs from the majority as the author, Professor János Rakonczai, consequently uses a specific geographical approach in order to profoundly describe the urgent challenges and policies of humanity's present and future. The scrutiny is versatile as both sectoral and thematic issues are introduced from global and regional perspectives in obvious structures. All principal aims – to incline readers for further co-thinking, for deepening their critical views, for encouraging the creation of personal opinions – are praiseworthy.



Though this book is wholeheartedly recommended in principal to scholars and students in the scientific fields of environmental protection, geopolitics, geopraphy, environmental engineering, the content might also be interesting and easily understandable for a readership from different disciplines as well as to reader eager to get deeper insight into the global socio-economic and political flows affecting the environment. The author supplemented all chapters with thematic maps, figures and photos which make the reading procedure not only scientifically but visually pleasant. Besides, up-to-date (sometimes astonishing and shocking) statistical data, historical and recent research results of world-renowned professionals from the scientific arena, and even many comparisons as objective and trustworthy evidences are increasing the reader's consciousness towards global problems.

Within the confines of the current review, I consistently go through all important themes, also highlighting the most thrilling data and information provided in the book.

The volume comprises three main chapters. The first one gives a theoretical overview and initiates an evolutionary approach to globalisation. As it was already mentioned, global environmental problems have been altering throughout the previous half a century. After World War II, hungers, then acid rains, and the hole on the ozone layer were in the scientific limelight. During the last three decades, overpopulation, climate change and water-related issues (that are undoubtedly interdependent on each other) have become urging socio-economic and enviromental problems worldwide. Consequently, the author considered these topics crucial and necessary to be elaborated in detail – along with other, thematically related issues.

The second chapter might well be seen as the spine of the book. Global problems and conflicts are examined and introduced thorougly in a clear and didactic structure. As a starting point, overpopulation and other population related issues are introduced. Due to the decrease in hunger, epidemics, and wars, the scale of population growth accelerated at unexpected rates. While 124 years were necessary for the population to grow by one billion during the 20th century, nowadays the same takes 12–14 years only. This increase shows many regional and local differences. The most affected areas are highly urbanised areas (54% of the global population lives there, mostly in megacities). In this chapter, income inequality is also analysed. Based on contemporary research results, the divergence of the highest and lowest social status groups is accelerating year by year – as one of the main characteristics of capitalism according to the works of Joseph Stiglitz and Thomas Piketty. At the beginning of 2017, the wealth of the eight richest people in the world equalled the total wealth of the 3.6 billion poorest people. In only 2017, the 500 wealthiest people increased their wealth by more than one trillion dollars (almost 25%). On the contrary, the share of people in extreme poverty (as living on less than 1.90 USD per day) has steadily been growing on all continents during the past few years.

Important issues influencing population growth the same way are infectious diseases and epidemics. The author provides a detailed introduction to these topics and critically underlines that, interestingly, everyday attention is mostly focused on wars, acts of terrorism, and traffic accidents, although AIDS and malaria cause more deaths separately than all former factors combined. Still, in terms of population topics, international migration became a hot topic due to its accelerating volume, especially in terms of economic and environmental migrants. In 1970, 2.3 per cent of the world's population was migrating, whereas the same value was 3.4 per cent in 2017 (equalling to more than 250 million people). The most spectacular migratory flows occurred in the case of Mexico, from where 12.3 million people moved to the US in 2017.

The next chapter (*Global climate change and environmental atmospheric problems*) deals in general with the composition of, and temporal changes in, the atmosphere. The results of different paleoclimatic researches offer a great overview of past climate changes on global and regional level. Rakonczai underlines that the history of the Earth involved a series of climate changes. Although no spectacular change can be detected in the life of individuals, it is already known that there have been much warmer and colder periods in the history of the Earth. As the author stresses, the process, background and major consequences of current climate change can mostly be explained through the changing athmospheric concentration of greenhouse gasses, global warming, seawater acidification, El Niño, the Great Ocean Conveyor Belt, precipitation conditions, desertification and volcanic activity. In order to emphasise the seriousness of these topics, he provides some thrilling information. For instance, just to mention some evidence on global warming: the annual maximum ice cover varied between 15.7 and 16.3 million km^2 in the 1980s, but in the last decade (2009–2018), it decreased to between 14.4 and 15.3 million km^2. Considering the trends, estimates assume that the Arctic Sea ice will totally disappear by 2040 (or even earlier). Another solid evidence for the global climate change are altering precipitation conditions and desertification. These are not simply natural phenomena but joint consequences of natural, social and economic processes. The situation is the worst in Africa, where two-thirds of the population lives in drought-prone areas. Deforestation, erosion, deflation are not only results, but accelerating factors for further negativ processes. Deforestation advanced southwards at 15–20 km per year on average (up to a sum of 400 km in the 1990s), and the Sahara expanded 5–6 km per year to the northwest. Other exampe are the gradual melting of permafrost areas, seawater acidification, severe floodings and the changing nature of the Global Ocean Conveyor Belt. As a praiseworthy part of several chapters, the author deliberitaly ends with forming a critical opinion on responsibility issues leading the readers towards further re-thinking.

The volume provides a detailed analysis of the Ozone Hole, including its evolution, its chemical and physical attributes, the differences between the Northern and Southern Poles, and the responsible materials and economic activities. Similarly, serious, but often neglected global problems are connected to acid rains, which are caused by three major factors: industrialisation, deficiencies in environmental regulations, and gas emissions associated with volcanic eruptions. The reader can find a lot of examples of the harmfulness and long-term effects of these phenomena. As the author stresses, they do not constitute a unified global problem, rather a combination of regional problems over huge areas that does not affect the entire world, but primarily industrial and urban areas where population density is the highest.

Among atmospheric problems, air pollution must also be mentioned as, according to WHO data, 92 per cent of the world's population is exposed to unsafe levels of air pollution, and an estimated three million deaths a year are linked to outdoor air pollution and 4.3 million to indoor air pollution. The reader can also find many information on health consequences of natural and anthropogenic air pollution.

A remarkable part of the book is dedicated to global water problems, which constitutes an important issue since, besides food, water is another 'bottleneck' for humans in the future, and the importance of water has already preceded that of food. Growing population, its food supply, and urbanisation have caused rapid growth in water use. Declining water resources and the population growth in many countries result in water scarcity or water stress (concerning quality and quantity as well). In 2015, about two-thirds of the people suffered from water stress, and 1.8 billion people lived in areas of water scarcity. According to the book, humanity used about 54 per cent of all available freshwater at the beginning of the third millennium, and this figure is expected to increase to 70 per cent by 2025. The annual increase of water use exceeds the rate of population growth: between 1950 and 2014, population increased by 2.87 times, and water consumption increased by 3.25 times. A relevant solution might be the the extraction of groundwater in many places, though the over-exploitation of groundwater also causes problems. Sad examples are for that irresponsible water use, such as in case of the Aral Sea, Lake Chad, Lake Urmia and Lake Poyang, just like the Yellow River, Colorado and Nile Rivers. Water pollution and flood risks are perfectly presented through regional and local examples. At the end, the book investigates water resources which are flowing through semi-arid areas and causing serious water conflicts that might lead to 'water wars' in the future, such as in Israel, Jordan, Syria, Turkey, Iraq, Egypt, and Ethiopia.

In connection with water, sea issues such as overfishing also pose a big problem. Between 1950 and 2006, the size of fishing areas has increased tenfold, now reaching 100 million km^2 and affecting the wildlife in at least one-third of the world's seas. On more than 30 per cent of the seas the signs of overfishing can clearly be detected. Another striking sign of overfishing is the size of the fish that are captured. Moreover, as a typical change in marine fishing, after the radical decline in the population of some species, previously less valuable species are being caught now. As one of the hottest environmental topics of the year 2019, the pollution of world seas, especially the appearance of masses of plastic waste seems to be the biggest problem. Eight million tonnes of plastic per year reaches the sea, but some calculations suggest the claim that the amount will be double of that this year. An important example is the so-called Eastern Garbage Patch, which later was renamed the Great Pacific Garbage Patch. It was already more than twice as large as the state of Texas in 2007, and was located in the northern Pacific Ocean between California and Hawaii. The waste in this 'plastic island' originates from the continents, and has been transported and shaped by ocean waves for a long time, causing enormous problems to wildlife. The water and air pollution by supertankers and tanker disasters are also investigated through many examples from the previous decades.

In the following parts of the volume, two small chapters are dealing with deforestation and the waste problem. According to the author, one of the most spectacular changes has been caused by the destruction of the natural forests of the world. About 8,000–10,000 years ago, approximately 62.2 million km^2 of land was covered by natural forests, close to 42 per cent of all land area. By 2015, this amount had decreased to below 40 million km^2, with significant regional differences. The waste problem is also mentioned as the amount of waste is increasing much more rapidly than the opportunities for its treatment or processing. The major factors of this growth are urbanisation, industrial growth, the emergence of consumer society, and changes in social habits. The huge increase in waste since the 1960s has become an increasingly difficult challenge for economically developed, consumption-oriented societies. It is no coincidence, therefore, that waste appeared as a major global problem. Many versions of future scenarios predict a catastrophic end due to environmental pollution.

The next part puts special emphasis on limits of non-renewable natural resources, especially hydrocarbons and noble metals. Based on the demand-supply relationship, it was not surprising that raw material price shocks occurred during the past decades. This economic process fundamentally changed the rate of raw material use, and further price explosions have led to a constant decline in the rate of increase in consumption. The author gives a detailed overview of oil and rare earth metals, and provides estimations about the ways and time frame of their use.

After Chernobyl and Fukushima, the utilisation and consequences of nuclear energy are obligatory issues for a book like this. In 2018, 450 nuclear power plant reactors were operating in 34 countries around the world, 57 were under construction, and 154 were at the planning stage. Nuclear energy has become a leading source of electricity production in many countries. In 2017, the share of nuclear power exceeded 30 per cent in 12 countries. The most challenging environmental problem related to nuclear energy is the safe disposal of the high-level radioactive waste of nuclear power plants and the further 250 research reactors in 55 countries around the world. An average power plant reactor generates approximately 27–30 tons of high and 200–350 m^3 of low-level and intermediate-level radioactive waste every year. Nuclear power plants had also generated 370,000 tons of high-level radioactive waste by the beginning of 2018, out of which 120,000 tons were reprocessed.

Fertile soils are the most important criterion for food production and they play a major role in meeting further anthropogenic demands. That is the reason why Chapter 11 is about soil. The associated problems mainly belong to three categories: the limitation of the size of arable land, a decline in the area of agricultural production due to environmental problems and urbanisation, and the continuously decreasing amount of productive area per capita. An improvement in the food supply of the growing population has been ensured by the increasingly intensive use of land in the past decades. Increasing yields are the result of the growing use of fertilisers, improving plant protection and, especially, irrigation, which contribute to higher crop yields and food security. Soil degradation has many causes and consequences. The causes include overgrazing, deforestation, improper agricultural practices and overproduction. A further cause is the withdrawal of agricultural land due to the development of settlements, industrial facilities and transport infrastructure. The most significant consequences are erosion, deflation, chemical degradation, physical degradation and the decrease in biodiversity, which is associated with all the above mentioned factors.

Last but not least, decreasing biodiversity is also a mainstream environmental problem. Humanity has become a new factor in the alteration of the natural environment on Earth – numerous examples of this can be found in earlier chapters of the book. Its role in the changes is, of course, less dramatic than that of the meteorite mentioned before, but its impact on wildlife is greater in terms of efficiency and speed than that of the glacial climate change. Appparent causes are habitat loss, a direct loss of wildlife, habitat fragmentation, pollution, spread of invasive species, and climate change.

Eventually, the author scrutinises human responses to environmental challenges in much detail. One can observe the development of legal and practical ways of enviromental protection as well as the role and responsibility of science and politics. For this reason, the author presents important earth summits, which fostered paradigm shifts, such as those in Stockholm (1972), Rio de Janeiro (1992), Johannesburg (2002), and, again, Rio de Janeiro (2012). Furthermore, based on sectoral divisions, global summits have been introduced (e.g. conventions on ozone, greenhouse gases, acid rains, marine environment, freshwater, natural protection, and waste disposal).

The examples provided in the book show not only our environmental responsibility, but also the power of human knowledge. The basic question concerning the future of humankind is when and how this knowledge might be mobilised to tackle global challenges both socially and economically. Another question is whether the moral responsibility of major powers for global matters will overcome their desire for power.

Levente Halász[1]

[1] Department of Tourism, Institute for Social Well-Being, Kodolányi János University, Székesfehérvár, Hungary. E-mail: halaszlevente@hotmail.com

CHRONICLE

In memoriam Andrija Bognár (1937–2019)

An eminent figure of Croatian geography, active member of the Hungarian community in Croatia, Professor Andrija (András) Bognár passed away on 26 April 2019. He contributed to a wide range of physico-geographical disciplines, including tectonic geomorphology, geomorphological mapping, applied geomorphology, geoecology, Quaternary and loess research but also published seminal papers in political and population geography and Hungarology, the science concerned with knowledge on ethnic Hungarians abroad.

Andrija Bognár was born on 9 March 1937 in Zdenci, the Slavonian region of Croatia. He was a primary school pupil in the hard times of World War II in South Baranja region and continued his studies in the grammar school of Požega town. During his studies at the University of Zagreb it proved to be difficult for him to decide between human (urban) and physical geography (geomorphology). His curiosity equally attracted him in both directions. After graduation, in 1965, he found employment in the secondary school of Beli Manastir, a small settlement in Baranja, which reached the urban status shortly before that date. After two and a half year teaching he managed to return to the capital and became assistant professor at the Faculty of Political Sciences of the University. He was interested in geopolitical problems such as the boundaries of Transylvania. However, he gradually got attracted to the problems of physical geography and geomorphology and defended his university doctor's thesis on Bansko (Brdo) Hill and the loess region of South Baranja.

The invitation from Academician Josip Roglić, a great figure of contemporary Croatian geography, to the Department of Physical Geography at the Univestity of Zagreb started his academic career. Andrija Bognár succeeded the retired Professor Roglić as head of the Working Group on Geomorphology. He became associate professor in 1982 on defending his dissertation on the geomorphology of Baranja, a benchmark work till now. At that time, he launched the major project of geomorphological mapping of Croatia, which provided an example for mapping the whole territory of Yugoslavia. In 1986 he was appointed extraordinary professor, in 1992 full professor and in 1998 external member of the Hungarian Academy of Sciences. Even after retirement he regularly lectured at the University of Mostar, the Military Academy of Rijeka and the College of Dubrovnik. His publications include more than 150 papers in geomorphology, geoecology as well as political and demographic geography, written in the changed political atmosphere after 1991.

His international appreciation is reflected in membership of various organizations, among others including the International Association for Quaternary Research (INQUA), from where he received a Special Award for his work in the Loess Commission, the International Association of Geomorphologists (IAG), where he was national delegate for a long period, and the Croatian Society of Natural Sciences. He founded the Association of Croatian Geomorphologists and had leading positions in the Croatian Geographical Society.

His Hungarian contacts were not limited to building 'bridges' between the Hungarian Baranya county and the Croatian Baranja region. He was among the founders of the Democratic Community of Hungarians in Croatia (1993) and the Croatian Society of Hungarian Science and Arts (1995). For his activities in these organizations he was awarded with the Kemény Zsigmond Prize of the Pro Renovanda Cultura Hungariae Foundation.

Professor Andrija Bognár also maintained close links with Hungarian geography, primarily with the Geographical Research Institute of the Hungarian Academy of Sciences, under the directorship of Academician Márton Pécsi, Professor Ferenc Schweitzer and Academician Károly Kocsis. Since 2009 he was one of the active members of the international Advisory Board of the Hungarian Geographical Bulletin. He participated in joint projects of geomorphological mapping and loess studies (for instance, on the Adriatic island of Susak). On behalf of the University of Zagreb he regularly organized Croatian-Hungarian geographical seminars for the staff of Hungarian universities and research institutes at wonderful venues (such as on the island of Hvar, in the Paklenica National Park). In 2006 he received the Teleki Sámuel Prize from the Hungarian Geographical Society.

No commemoration could be complete without making at least brief allusions to his colourful personality. During our journeys into the world, organized by his favourite Hungarian colleague, Éva Kis, he proved to be a cheerful companion and enthusiastic partner in discussions. He was open to any new experience and curious about the novelties the world can offer to him. However, as he remarked, returning from a travel around the world, he regarded himself 'a man of oriental kind', by which he meant that he found the harsh turmoil of the Western society burdensome and could not identify himself with all of its values. He rather felt at home in the authority-based hierarchy of his own environment, he was more accustomed to that. Those who liked him accepted this attitude.

Andrija Bognár will be missed and remembered by many: friends and colleagues in geography, both in Croatia and Hungary and, in fact, in many countries of the world he visited.

Dénes Lóczy

In memoriam Kazimierz Klimek (1934–2019)

Polish physical geography has lost one of his charismatic figures, Professor Kazimierz Klimek on 16 April 2019. He was an internationally renowned expert in the geomorphology, paleogeography, nature conservation and environmental sciences of the Tatra Mountains and Silesia and a great friend of Hungarian geography.

He was born in Biecz, a small town in Małopolska province, on 30 January 1934. Between 1952 and 1956 he studied geography at the Jagiellonian University of Kraków. His master thesis was entitled 'Geomorphological evolution of the Solinka Basin, Bieszczady'. After graduation, he worked for several years as a geography teacher in Kraków. In the years 1960–1979 he was a research worker at the Department of Geomorphology and Hydrology in the Institute of Geography of the Polish Academy of Sciences in Kraków. From 1979 to 1991 he was the head of the Department of Nature Conservation at the Polish Academy of Sciences.

A typical representative of Polish geographers eager to explore the world, in 1968 he participated in his first major scientific expedition to southern Iceland. Then in the years 1974–1980 he headed seven expeditions organized by the Institute of Geography of the Polish Academy of Sciences to Mongolia. The scientific results of these expeditions were summarized in publications such as 'Contemporary fluvial processes and sculpture of the Skeiðarársandur plain (Iceland)' (1972), 'Vertical zonality in the southern Khangai Mountains (Mongolia)' (1980), 'Results of the Polish-Mongolian Physico-Geographical Expedition by Polish-Mongolian Physico-Geographical Expedition' (1980). In 1996, he led an expedition to Svalbard. He build widespread international links during his scholarships to the University of Uppsala (1967), University of Bucharest (1973), Keele University (1978) and Bulgaria.

Kazimierz Klimek became extraordinary professor in 1982 and a few years full professor of the Faculty of Earth Sciences at the University of Silesia in Katowice and the head of the Palaeogeography of Stokowo-Valley Systems at the Department of Paleogeography and Quaternary Paleoecology at the Faculty of Earth Sciences of the University of Silesia. At that time his main research areas were the geomorphology of and human impact on valley systems. He also published important papers on nature conservation and environmental protection (the effect of industrial emissions on ecosystems in Silesia, ahtropopressure in selected morphoclimatic zones) too. In addition to membership in several committees of the Polish Academy of Sciences, between 1991 and 1993 he was president of the Scientific Council of the Tatra National Park.

As permanent participant of bilateral Polish-Hungarian seminars in the 1990s, he acquired many friends among Hungarian geographers. He will be remembered as an outstanding scientist and lecturer, educator of many generations of geographers, an optimistic man of great heart and mind, righteous and noble, with helpful disposition, devoted to the community, who enjoyed the respect of all who knew him. He is mourned by wife, son, daughter-in-law and grandson along with a great number of geographer friends.

Dénes Lóczy

GUIDELINES FOR AUTHORS

Hungarian Geographical Bulletin (formerly Földrajzi Értesítő) is a double-blind peer-reviewed English-language quarterly journal publishing open access **original scientific works** in the field of physical and human geography, methodology and analyses in geography, GIS, environmental assessment, regional studies, geographical research in Hungary and Central Europe. In the regular and special issues also discussion papers, chronicles and book reviews can be published.

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Aagaard, T., Orford, J. and Murray, A.S. 2007. Environmental controls on coastal dune formation; Skallingen Spit, Denmark. *Geomorphology* 83. (1): 29–47.

Books:

Pye, K. 1987. *Aeolian Dust and Dust Deposits.* London, Academic Press.

Book chapters:

Kovács, J. and Varga, Gy. 2013. Loess. In *Encyclopedia of Natural Hazards.* Ed.: Bobrowsky, P., Frankfurt, Springer, 637–638.

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