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BIOPHYSICAL CRITERIA APPLICATION FOR DELIMITATION OF AREAS WITH NATURAL CONSTRAINS (ANC) IN SLOVAKIA

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Abstract

The paper represents the final version of a redefinition of Areas with Natural Constrains (ANC) of the Slovak Republic according to the new rules of the European Commission (EC) by Article 32 and 33. Joint Research Centre EC (JRC) in Ispra has identified 8 biophysical criteria: two climatic criteria, four soil criteria, one integrated criterion (climate and soil) and a slope as a topographic criterion. Applying the guidelines of the EC, assessment of all biophysical criteria were processed and 5 criteria were acknowledged for Slovakian conditions. In addition, a new aggregate criterion was proposed and approved by JRC. All municipalities of the Slovakia (a level NUTS 5) containing the current database of the Statistical Office were included into the simulation. In each municipality, area of Land Parcel Identification System to be eligible for EU subsidy payments was identified. A GIS algorithm was used to calculate the share of agricultural land which meets the biophysical criteria at the level of 60% municipality area, i.e. data on the soil and landscape were converted into a grid with a spatial resolution of 20 m. A new aggregate criterion is based on the assumption that there is possible to identify spatial pattern of each of the individual criteria, avoiding the case, that the same area could be counted twice. The last version of the methodology was approved by JRC commission EC and Map of the ANC serves as a basis for the farmer´s payment subsidies in the frame of EAFRD (European Agricultural Fund for Rural Development).

Keywords: areas with natural constrains, biophysical criteria, municipality, Slovakia

INTRODUCTION

In the European Union, less-favoured area (LFA) is a term used to describe an area with natural handicaps (lack of water, climate, short crop season and tendencies of depopulation), or that is mountainous or hilly land, as defined by its altitude and slope (Council Regulation (EC) No. 1698/2005, Eliasson, Terres, Bamps eds. 2007). In 2011, the European Commission published a new proposal for a Regulation of the European Parliament and of the Council on Support for Rural Development by the European Agricultural Fund for Rural Development (EAFRD) which the conditions for payments are defined in Articles 32 and 33. The need to redefine less favourable areas on the basis of the new criteria has been the result of criticisms by the Court of Auditors in The Hague. They criticized the wide range of criteria applied in each EU country, leading to significant disparities. They recommended a review of the criteria applied so far and the establishment of new criteria for less favourable areas within all EU countries. It is important that the Commission omitted demographic criteria (population density, share of agricultural workers in the economically active) from the current solutions, as these criteria suppress natural conditions and are difficult to compare across EU Member States.

The European Commission, with the help of researchers from the Joint Research Centre (JRC in Ispra, Italy), has established 8 biophysical criteria, which can provide a suitable basis for an objective and unambiguous classification of less favourable areas later renamed as Areas with Natural Constrains (ANC). It means that two climatic criteria, four soil criteria, one integrated criterion (climate and soil) and slope as a topographical measure were reviewed, tested, simulated and 5 criteria from the list also applied.

The aim of the paper is to present methodological procedures: database analyses, models and georeferenced data processing of individual biophysical criteria which were developed for Areas of Natural Constrains in Slovakia. The work included the processing of soil properties, topographic and climatic databases available in the national databases as well as auxiliary data. The main methodologies were applied according to guidelines by Van Orshoven, Terres, Eliasson (eds) 2008 and Van Orshoven, Terres, Tóth 2013. In addition, a new aggregate criterion was proposed for ANC delineation which was tested and approved by JRC. The result is a map of Areas with Natural Constrains which meeting the Articles 32 and 33. Developed methodology for Slovakia was approved by JRG commission (EC) after many consultations, and serves as basis for farmer´s subsidies up to now. Mountains areas and areas with specific constrains which were assessed separately and are not subject of this study.

Similar works were created in the Czech Republic (Vopravil *et al.* 2010) and Hungary (Pásztor, Szabó, Bakacsi 2010), however comparisons were not possible due to the national nature of the task.

MATERIALS AND METHODS

Soil mapping in Slovakia has a long tradition. It is based on a General Survey of Agricultural Land in the former Czechoslovakia in the 1960s. The survey collected a large amount of map data at a scale of 1: 10,000 (soil types, soil types, skeleton, wetting, parent substrates) and analyzed about 160,000 soil samples. It uses a rich database of an information system on soil and landscape, managed and administrated by the Soil Science Research and Conservation Research (Skalský & Balkovič 2002, Saksa *et al.* 2009). These databases are:

- Georeferenced database of agricultural soils of Slovakia (GDPPS) (Skalský 2005), which integrates soil profile and map outputs of the General Survey of Agricultural Land of the former Czechoslovakia (Němeček *et al.* 1967). The following data were available: (i) data on special and selected soil profiles and basic soil probes (digital data are only available for selected areas (Saksa *et al.* 2009); (ii) vector data (digital version is available for part of the area of Slovakia (Saksa *et al.* 2009). As output e.g. Soil Map of Slovakia was generated in the scale 1:400,000 (Hraško *et al.* 1993).
- Database of soil-ecological evaluation units (BPEJ), which implicitly includes a vector layer. Maps were developed at a scale of 1: 5,000 and digitized in 1993 as polygonal vector layer in ESRI Shape, with a total of approximately 8,000 individual types of BPEJs (Linkeš, Pestún, Džatko 1996, Džatko, Sobocká, *et al.* 2009).
- Database of the Partial Soil Monitoring System (ČMS) (Kobza *et al.* 2009), which contains profile data on the properties for selected monitoring probes on the agricultural land (latest version in Kobza *et al.* 2019).
- Geochemical Soil Atlas of Slovakia (GCHA) (Čurlík & Šefčík 1999), which contains data of soil properties A and C horizons of 5,200 soil profiles (agricultural and forest land).
- Climatological data of selected meteorological stations registering statistically significant climatological 30-year period database for the calculation of the drought index and climate indicators.
- Other auxiliary available databases providing data according to the requirements of the EC.

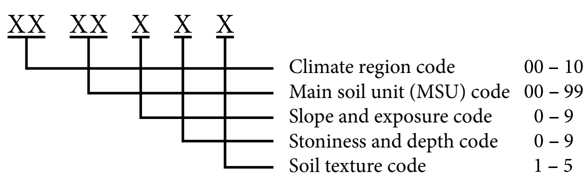

Figure 1 Structure of the BPEJ code

The BPEJ´s vectorised database presents an important tool used at the national level for several purposes, such as: i) assessment of the soil quality of agricultural land, ii) legislative protection of soils, iii) spatial planning, iv) land take legislation, v) land consolidation, vi) re-cultivation measures and others. The soil-ecological evaluation unit (BPEJ) represents a quasi-homogeneous spatial unit expressed by a 7-digit code (Fig. 1).

The available databases were processed according to the EC claims. In terms of processing georeferenced databases, the most modern means and tools of GIS products were used, as well as progressive model solutions, spatial interpolation methods, regression kriging, *etc.* GIS tools, commercial product ArcMap Version 9.3 f. ESRI, were used in the calculations of the spatial unit's classification of (municipalities) into defined areas with natural constraints at 60% area.

From 8 biophysical criteria only 5 criteria met conditions of the JRC EC for Slovakia. Climate criteria like Low temperature, Dryness and Climate-Soil Criterion Excess Soil Moisture were evaluated and classified as not applicable in the Slovakian conditions (Tab. 1). However, there were developed one new (soil) criterion – aggregate criterion which has been presented by paper's authors and recognized by EC JRC. A GIS algorithm was used to calculate the share of agricultural land which meets the biophysical criteria at the level of 60 % municipality area.

The process of selection of some climate criteria for Slovakia has been discussed in Takáč *et al.* 2010,

Table 1
Biophysical criteria not applicable for Slovakia

Criterion	**Definition**	**Threshold**
CLIMATE		
Low temperature	Length of Growing Period (number of days) defined by number of days with daily average temperature > 5 °C (LGP_{t5}) OR	≤ 180 days
	Thermal-time sum (degree-days) for Growing Period defined by accumulated daily average temperature > 5°C.	≤ 1500 degree-days
Dryness	Ratio of the annual precipitation (P) to the annual potential evapotranspiration (PET)	P/PET ≤ 0.5
CLIMATE AND SOIL		
Excess Soil Moisture	Number of days at or above Field capacity	≤ 230 days

Table 2
Application of biophysical (soil, terrain) criteria in Slovakia

Biophysical criterion	**Criterion application**
Limited Soil Drainage	Applied individually
Unfavourable Stoniness	Applied individually
Unfavourable Soil Texture – Sandy Soils	Applied individually
Shallow Rooting Depth	Applied individually
Steep Slope	Applied individually
Aggregate criterion	Aggregate criterion was developed on the delimitation of these criteria: • limited soil drainage, • unfavourable stoniness, • unfavourable soil texture – sandy soils, unfavourable soil texture – heavy clay soils, unfavourable soil texture – organic soils, • shallow rooting depth, • poor chemical properties (salinity + sodicity), • steep slope

and further confirmed in Takáč (2015). The procedure for soil criteria incl. aggregate criterion and terrain criterion classification were described in Sobocká *et. al.* 2011, Sobocká *et al.* 2013, Sobocká, Skalský 2013, 2014. In the Table 2 we present an overview of the criteria applied in the conditions of Slovakia which were tested and approved by the Joint Research Centre EU (JRC).

RESULTS AND DISCUSSIONS

In the following the procedure of the Slovak Republic is described when applying different biophysical criteria, as well as their testing by the JRC and the resulting solution:

1st Criterion: Limited soil drainage (BK1) (Van Orshoven, Terres, Tóth 2013)

Limits: areas which are waterlogged for significant duration of the year with:

- moist up to 80 cm from the surface more than 6 months, OR
- moist to 40 cm over 11 months, OR
- weak poorly drained soils, OR
- very weak poorly drained soils, OR
- Gleyic colour pattern to 40 cm from the surface.

JRC required to develop a rate hydro-morphisms expression on the basis of diagnostic features characteristic for national soil classification (VÚPOP, SPS 2000). In addition, it was also necessary to correlate soil types and subtypes with the World Reference Base for Soil resources (IUSS Working Group WRB 2006, 2007). A correlation of the hydromorphic soil features of the Morphogenetic Soil Classification System of Slovakia (MSCS) with WRB (2006, 2007) is shown in the Table 3.

Table 3

A correlation of the hydromorphic soil features (MSCS 2000) with the WRB system (2006, 2007)

MSCS 2000		**WRB (2006, 2007)**	
Soil type	Glej	Reference soil group	Gleysol
Soil subtype	modal cultizemic peat organozemic	Qualifiers (prefixes or suffixes)	Haplic Anthric Histic Ombric
Variety	saturated acid calcareous thionic	Qualifiers (prefixes or suffixes)	Eutric Dystric Calcaric Thionic
Form	–	Some qualifiers and suffixes	

The database of BPEJ was used for spatial delimitation. The main soil unit (MSU) (Džatko, Sobocká *et al.* 2009) has a close relation to the Morphogenetic soil classification system of the SR (MSCS 2000) (VÚPOP, SPS 2000). Some codes of MSU meet several criteria for involvement them into several reference soil group (RSG) according to hydromorphic morphological soil characteristics. First of all, Gleysols and Stagnosols or Planosols belong to the most unfavorable areas, especially in combination with very heavy soils. A correlation of Gleysols (incl. Gleyic soil subtypes), and Planosols or Stagnosols (incl. their soil subtypes) and their diagnostic features is shown in the Tables 4 and 5.

Several groups of hydromorphic characteristics were developed and used:

Group A1 Wet soils within 80 cm from the surface for over 6 months

Characteristics: correlated data MSCS (2000) + WRB (2006, 2007)

- to 80 cm from the surface features of periodical waterlogging (10 – 80% mottling)
- presence of Eluvial (Albic) horizon

Table 4
A brief correlation of some diagnostic features of soil types Glej (MSCS 2000) and Gleysol (RSG) WRB (2006, 2007)

Glej (MSCS 2000):	**Gleysol (WRB 2006, 2007)**
Soils having in topsoil Gleyic reduction horizon: • Gleyic reduction horizon: grey to greyish-green (Munsell colour charts hue GY, G, BG) with small colour contrast pattern in matrix > 90% • Gleyic reduction-oxidation horizon: mottles alternating reduction and oxidation mottling pattern in matrix 10 – 90%, clusters of hydrated Fe, • Gleyic oxidation horizon: presence of mottling pattern of rusty oxides and hydroxides in matrix, presence of grey colour <10%	Soils having within 50 cm of the mineral soil surface a layer 25 cm or more thick has reducing conditions in some parts and Gleyic colour pattern throughout • 90% or more reductimorphic colours which comprise neutral white to black (Munsell hue N1 to N8, or bluish to greenish Munsell hue (2,5 Y, 5 Y, 5 B), or • 5% or more (exposed area) mottles of oximorphic colours, which comprise any colour excluding reductimorphic colours.

Table 5
A brief correlation of some diagnostic features of soil types Pseudoglej (MSCS 2000) and Planosol, or Stagnosol (RSG) WRB (2006, 2007)

Pseudoglej (MSCS 2000)	**Stagnosol or Planosol (WRB 2006, 2007)**
Soils having in topsoil Pseudogleyic horizon: • Mosaic pattern alternating of rusty, ochric and grey colours in a matrix with high contrasts (oxidation mottles with wet chroma >5, reduction mottles hue Y or G. • Presence in matrix > 80%. • Presence of Fe a Mn pellets • Presence of eluvial or albic horizon	Soils having within 50 cm of the mineral surface in some parts reducing conditions for some time during the year and in half or more of the in half or more of the soil volume single or in combination Stagnic colour pattern and Albic horizon**.** • Mottling on surface peds are lighter (at least one value unit) and paler and the ped interiors are more reddish (at least one hue unit) and brighter (at least one chroma unit) • It has more than 50% of soil volume Note: at Planosols also abrupt textural change is required; in the MKSP 2000 this feature is not acknowledged.

- presence of Mn a Fe pellets
- periodical saturation of soil matter with low hydraulic conductivity

Group A2 Wet soils within 40 cm for over 11 months

Characteristics: correlated data MSCS (2000) + WRB (2006, 2007)

- Gleyic reduction-oxidation horizon: mottling with alternating reduction and oxidation mottles in matrix 10 – 90%, clusters of hydrated Fe,
- Gleyic oxidation horizon: presence of rusty oxides and hydroxides, presence of grey colour < 10%
- Presence of iron and manganese oxides
- Accumulation of weakly decomposed organic matter on topsoil
- Shallow level of groundwater and its significant influence of soil profile

Group B1 Poorly drained soils

Characteristics: Soil Survey Manual (Soil Survey Division Staff 1993) – poorly drained:

- Heavy soil texture
- Low hydraulic conductivity
- Periodically or long-term waterlogged soil

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Group B2 Very poorly drained soils
Characteristics Soil Survey Manual, (Soil Survey Division Staff 1993) – poorly drained:
- Heavy soil texture
- Low or very low hydraulic conductivity
- Long-term waterlogged soil

Group C Gleyic colour pattern within 40cm from the surface
Characteristics: correlated data MSCS (2000) + WRB (2006, 2007)
- Gleyic reduction horizon: grey to greyish-green (Hue GY, G, BG) s with small colour contrast pattern in matrix > 90%
- Accumulation of weakly decomposed organic matter on topsoil
- Shallow level of groundwater and its significant influence of soil profile

Testing of the criterion BK1 by the JRC EC resulted in the final approved version (Tab. 6).

Table 6
Evaluation of the criterion Limited soil drainage (after correction)

MSU code	Soil type (subtype) (MKSP 2000)	Reference soil group (WRB 2006, 2007)	Met criteria		
			A1 A2	B1 B2	C
08	Gleyic Fluvizems, loamy (on topsoil stagnic features)	Gleyic Fluvisol or Endogleyic Stagnosol, loamy soils (stagnic colour pattern on the surface)	A2		
09	Gleyic Fluvizems, loamy to clayey (on topsoil stagnic features)	Gleyic Fluvisol or Endogleyic Stagnosol, loamy to clayey soils (stagnic colour pattern on the surface)	A2		
12	Gleyic Fluvizems, clayey texture	Endogleyic Fluvisol, clayey texture	A1		
13	Gleyic Fluvizems, clays	Endogleyic Fluvisol (Clayic), clays	A1	B2	
27	Gleyic Ciernica, calcareous or non-calcareous, clayey	Endogleyic Phaeozems (Calcaric) or Gleyic Phaeozems (Clayic), clayey texture	A1	B1	
28	Gleyic Ciernica, calcareous or non-calcareous, clays	Endogleyic Phaeozems (Calcaric) or Gleyic Phaeozems (Clayic), clay texture	A1	B2	
51	Pseudogleyic Hnedozem locally Pseudogleys from loess and polygenetic deposits, clayey texture	Stagnic Luvisols, locally Stagnosol (Planosol) from loess and polygenetic deposits, clayey texture	A1	B1	
56	Pseudogleyic Luvizems and Luvizemic Pseudogleys from loess and polygenetic deposits, loamy to clayey texture	Stagnic Luvisols and Luvic Stagnosols (Planosol) from loess and polygenetic deposits, loamy to clayey texture	A1		
57	Pseudogleys from loess and polygenetic loamy deposits, on topsoil loamy to clayey texture, locally clays	Stagnosols (Planosol) from loess and polygenetic loamy deposits, on topsoil loamy to clayey texture, locally clays	A1	B1	
58	Pseudogleyic Luvizems and Pseudogleys, eroded on steep slopes	Stagnic Luvisols and Stagnosols (Planosol), eroded on steep slopes	A1	B2	

69	Pseudogleyic Kambizems from flysh weathered rock, loamy texture	Stagnic Cambisols (Siltic) from flysh weathered rock, loamy texture	A1		
70	Pseudogleyic Kambizems from flysh weathered rock, clayey to clays	Stagnic Cambisols (Clayic)	A1	B1	
71	Pseudogleyic Kambizems from deluvial loamy deposits, loamy to clayey texture, locally clays	Stagnic Cambisols from deluvial loamy deposits, loamy to clayey texture, locally clays	A1	B1	
72	Pseudogleyic Kambizems with presence of water ground level within 60 – 80 cm, from various parent materials, loamy to clayey texture, locally clays	Stagnic Cambisols (Clayic) with presence of water ground level within 60 – 80 cm, from various parent materials, loamy to clayey texture, locally clays	A1		
84	Pseudogleyic Kambizems on steep slopes, loamy to clayey texture, locally clays	Stagnic Cambisols on steep slopes, loamy to clayey texture, locally clays	A1		
85	Pseudogleyic Luvizems and Luvizemic Pseudogleys, from polygenetic deposits with admixture of skeleton, loamy texture	Stagnic Luvisols and Luvic Stagnosols from polygenetic deposits with admixture of skeleton, loamy texture	A1		
89	Pseudogleys from polygenetic loamy deposits with admixture of skeleton, loamy to clayey texture	Stagnosols (Planosol) from polygenetic loamy deposits with admixture of skeleton, loamy to clayey texture	A1	B1	
94	Gleys, loamy to clayey texture	Gleysols, loamy to clayey texture		B2	C
98	Gleys, clayey to clays	Gleysols (Clayic), clayey to clays		B2	C

2nd Criterion: Unfavourable stoniness (BK2) (Van Orshoven, Terres, Tóth 2013)

Limits: relatively high content of coarse-grained material (vol. %). Limit of stoniness:

- content ≥ 15% vol. of coarse-grained material including outcrop of rock on the surface (stoniness)

The EC required content ≥ 15% by volume of coarse material in top horizon including rocks and boulders on the surface (FAO 2006). It should be noted that the Slovak Republic does not have databases that represent the areas with this limit. Two databases are available in Slovakia, which are mutually intersected:

1 Database of the General Survey of Agricultural Land (KPP) (the scale 1:10 000);

2 Database of Evaluated soil-ecological units (BPEJ) (the scale 1:5 000).

No databases (KPP soil profile 160 000 records) meet unfavourable stoniness criterion limit of the EC. Stoniness in the KPP maps was evaluated (classified) on the size of the skeleton (gravel, stone) and skeleton content into four classes (Tab. 7). Similarly, the BPEJ data are derived from the KPP database and cannot interpret the limit on 15%.

Delimitation of the criterion unfavourable stoniness was made on the base of KPP maps because these maps are more accurate to attribute more detailed description stoniness in topsoil and subsoil (Sobocká *et al.* 2013). Vector data within KPP maps at a scale of 1:10 000 were used to the delimitation of skeletal soils for topsoil and subsoil. The database KPP is applied these categories: 3 moderately skeletal (25 – 50% [vol.]), and 4: strongly skeletal (50 – 100% [vol.]). So, Slovakia applied area of unfavourable stoniness with content of coarse material with limit ≥ 25%.

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Table 7
Stoniness database of the KPP and BPEJ

Code of stoni-ness (KPP)	Characteristics	Skeleton content [vol.] in top horizon (%)	Code of stoni-ness (BPEJ)	Characteristics
1	Without skeleton	0 – 10	0	Soils without skeleton (skeleton content [vol.] to thickness 0.6 m less than 10%)
2	Weakly skeletal	10 – 25	1	Weakly skeletal soils (stone content [vol.] in top horizon 5 – 25 %, in subsoil horizon 10 – 25%)
3	Moderately skeletal	25 – 50	2	Moderately skeletal soils (skeleton content [vol.] in top and subsoil horizon 25 – 50%)
4	Strongly skeletal	50 – 100	3	Strongly skeletal soils (skeleton content [vol.] in top horizon 25 – 50%, in subsoil horizon more than 50%; in the case with alternation of moderately or strongly skeletal soils also 25 – 50%)

3rd Criterion: Unfavourable soil texture – sandy soils (BK3) (van Orshoven, Terres, Tóth 2013)
Limits: Texture class in half or more (cumulatively) of the 100 cm soil surface is sand, loamy sand defined as:

$$\text{silt\%} + (2 \times \text{clay\%}) \leq 30\%$$

Slovak experts calculated the criterion for identifying sandy soils only for top horizon, although the updated version of the EC methodology identifying areas with ANC sets the limit so that the sand or loamy sand represents half or more (cumulative) layer 0 – 100 cm from the surface. In the light of JRC EC comments we have decided to make testing. The aim was to determine to what extent delimited area has corresponded to the new criteria.

As the data source on subsoil we used maps of soil texture (KPP) at scale 1: 10.000 (Nemeček *et al.* 1967), which indicates the size distribution of soil in the topsoil and subsoil layer (0 – 30 and 30 – 60 cm). Given that the application of sand content in the topsoil (Balkovič *et al.* 2010) represents a large extent independent spatial model, for the mutual comparison we used point a regular point grid with a resolution of 100 × 100 m, to which the data were taken over from the map of soil texture as well as from the spatial model of sand content and apply for areas with a valid criterion of the sand content. By this way we could eliminate disagreements arising from different spatial detail line border in soil map units, and in a spatial model. For further analysis, we used a total of 15,567 points with data on soil texture (according to the Novak classification of fraction <0.01 mm) for topsoil and subsoil. We also selected all soil profiles within a database of soil profiles (AISOP, Linkeš *et al.* 1988) within area of the municipalities and meet sandy soils criteria. The database AISOP contains measured soil profile data in several grain size fractions including clay (fr. <0.001 mm), silt (0.001 – 0.05 mm), sand (fr. 0.05 – 2.0 mm) and also the fraction of the total clay (fr. <0.01 mm). Finally, for further analysis, we used a total of 640 soil profiles focusing on:

a) assessment of the representation frequency of different soil textures in the subsoil that have been identified as having sandy texture in the model of sand content in topsoil (Balkovič *et al.* 2010);
b) analysis the structure of particle size distribution of soils with light texture (fr. content. <0.01 mm, 0 – 20%) both in relation to the sand content as well as to the value set by the EC for identifying sand

and loamy sand (ISSAND = SILT + 2* CLAY, wherein the ISSAND is indicator of textural classes (%), SILT is content (%) of the fr. from 0.002 –0.05 mm, and CLAY is content (%) of the fr. <0.002 mm.

The percentage of subsoil texture of (30 – 60 cm) within the area delimited as sandy soils is shown in Figure 2. The graph shows that a significant majority of soils (94.8%) has subsoil containing fr. <0.01 mm below 20% (sandy and loamy soils). Only 5.2% of the area have soils with subsoil sandy loam or heavier.

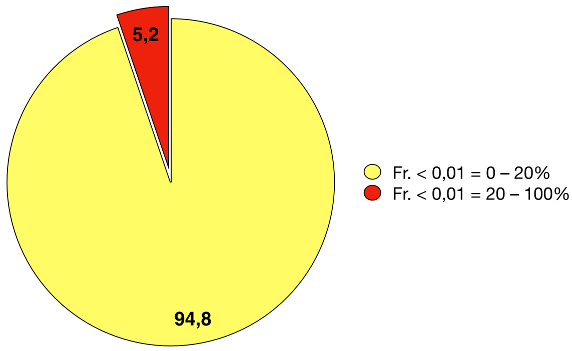

Figure 2 The percentage of subsoil texture (30 – 60 cm) within the area delimited as sandy soils

Due to fact that for sandy soil areas delimitation we have used only the criterion of sand content (content fr. 0.05 – 2.0 mm over 80%), we decided to test the consistency of our delimitation with delimitation criteria as set by EC with soil profile data from national soil profile database AISOP (Fig. 3).

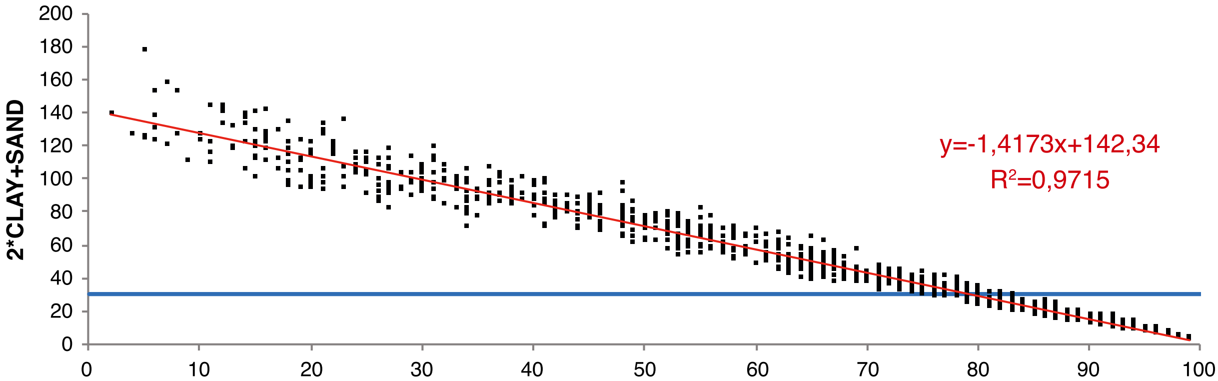

Figure 3 Relationship between sand content (%, fr. 0.05 – 2.0 mm) and ISSAND criterion (%) defined by EC in sample set of 640 soil profiles (blue line corresponds to threshold value of ISSAND = 30%)

We calculated the ISSAND value from the AISOP data on fr. <0.001 mm and fr. 0.001 – 0.05 mm content (%). Prior to ISSAND value calculation, the fraction <0.001 mm was re-calculated to fr. <0.002 mm value by published pedo-transfer function (Nemeček *et al.* 2001); the content of other fractions (silt, sand) was subsequently corrected so that the sum with the adjusted value of fr. <0.002 mm did not exceed 100%. From the Figure 3 it is visible that in the delimited sandy soil area the criterion of sand content > 80% we have used for delimitation corresponds to threshold value of ISSAND = 30% set by EC. We identified texture class of subsoil layer for delimited area of sandy soil from the soil texture map which content does not fully corresponds to classes of texture triangle. For this reason, we decided to analyse the subsoil textural classes with soil texture data (sand, silt, and clay content) coming from AISOP database.

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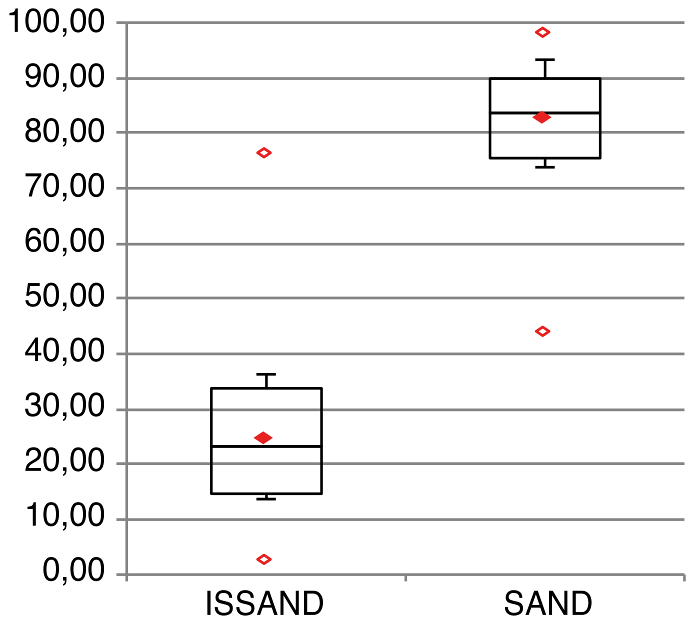

Figure 4 Distribution of sand content (%) and ISSAND (%) values calculated for coarse soils with fr. < 0.01 mm less than 20% (box plots show median, upper and lower quartile, whiskers 10% and 90% quantiles, empty diamonds show minimum and maximum values, full diamond show arithmetic mean*)*

From the Figure 4 is visible that SAND and ISSAND values distribution is relatively narrow and most of the values lie in range of 15 – 20% of the respective characteristics. Most of the observations from the delimited area of sandy soils are below threshold value of ISSAND = 30%; as well as the most observations are in SAND value interval more than 80%. Minor part of observations is either above or below threshold value of ISSAND or SAND value, respectively. This could be explained by some inconsistency of the used soil texture classification compared to international conventions in classifying soil texture.

From the analysis we found out that criterion we have used for sandy soil areas delimitation (sand content > 80%) fully corresponds with threshold values as set by JRC EC, where the sandy soils are defined as soils having sum of the silt content with sand content multiplied by two is less than 30%. Using of national soil inventory maps on soil texture classes distribution showed that about 95% of sandy soil areas is delimited exactly according to JRC EC criteria because of coarse soil texture of the subsoil (sand and loamy sand with fr. < 0.01 mm less than 20%). Subsequent analysis of particle size distributions showed out that soil texture characteristic of the soils is in good agreement with EC criteria. About 5% of the area delimited to sandy soils does not meet the JRC EC criteria because of finer soil textures in the subsoil. We conclude that criterion for sandy soils identification (sand content more than 80%) fully corresponds to threshold value set by JRC.

4th **Criterion: Shallow rooting depth (BK4)** (Van Orshoven, Terres, Tóth 2013)

Limits: depth (cm) from soil surface to coherent hard rock or outcrops, limit ≤ 30 cm.

To calculate the area of shallow soils a system soil-ecological evaluation units (BPEJ) Thickness encoding the soil is shown in the Table 8. This criterion is linking to areas of Lithic Leptosols and Haplic Leptosols (extreme skeletal soils), shallow Cambisols, Cambic Leptosols and shallow Rendzic Leptosols (Tab. 9). Testing of this criterion was accepted by JRC EC.

Table 8
Soil profile thickness encoding in the BPEJ system

Code	Characteristics	Limits
0	Deep soils	> 60 cm and more
1	Medium deep soils	30 – 60 cm
2	Shallow soils	< 30 cm

Table 9
Main soil units in the BPEJ system meeting criterion of rooting depth

Code MSU	Characteristics	Correlation with units WRB 2006, 2007
76	Cambizems arable (or modal) and Rankers cambizemic, shallow, from weathered crystalline rocks, moderately heavy or heavy	*Cambisols and Cambic Leptosols, shallow, developed from weathered crystalline rocks, loamy or sandy texture
77	Cambizems arable (or modal) and Rankers cambizemic, shallow, from weathered igneous rocks and from deluvial sediments, moderately heavy	*Cambisols and Cambic Leptosols, shallow, developed from weathered volcanic rocks, loamy texture
78	Cambizems arable (or modal) and Rankers cambizemic, shallow, from weathered materials of flysh, moderately heavy or heavy locally very heavy	* Cambisols and Cambic Leptosols, shallow, developed from weathered flysh rocks, loamy or clayey texture, locally clays
79	Cambizems arable (or modal) and Rankers cambizemic, shallow, from other parent materials, moderately heavy or light	* Cambisols and Cambic Leptosols, shallow, developed from other parent substrates loamy or sandy texture
90	Rendzinas arable (or modal), shallow, moderately heavy or light	Rendzic Leptosols, shallow, loamy or sandy texture
97	Litozems modal and rankers modal (extremely skeletal soils), content of skeleton in whole profile more than 80%, or rock outcrops to 0,1 m from surface	Lithic Leptosols and Leptosols (Skeletic), extreme skeletic soils, content of skeleton is more than 80% or rock outcrop

* Very weakly developed Cambic horizon can be situated in mountain areas with total thickness to 30 cm

5th Criterion: Steep slope (BK5) (Van Orshoven, Terres, Tóth 2013)

Limits: it is change of elevation due to planimetric distance to the limit: ≥ 15%.

To determine the extent of agricultural soils with sloping area (percentages) there was calculated on the basis of very precise digital terrain model (DTM) with a raster resolution of 20 m. Conversion sloping area has been made in view of new defined territorial unit – municipality). The percentage extension of sloping area was calculated on the basis of very precise mathematical model by delimitation of defined areas with slopes ≥ 15%. Methodology for delineation of steep slope area was clearly agreed.

6th Aggregate criterion (BKA)

Slovak Republic has proposed an application of so-called aggregate criterion, which is based on the fact that the municipality area may be affected by more natural handicaps, although they individually do not reach the fixed criterion (60%). Aggregate criterion can be identifying as spatial pattern of each of the individual criteria, avoiding the case, that the same area could be counted twice. These criteria were included within processing: 1) steep slope, 2) limited soil drainage, 3) unfavourable soil texture – sandy soils, 4) unfavourable soil texture – heavy clay soils, 5) unfavourable stoniness, 6) shallow rooting depth, 7) unfavourable soil texture – organic soils, 8) poor chemical properties (salinity + sodicity).

The calculation of aggregate criteria was done as overlay layers of different criteria (LPIS area in communities). Before calculating vector layers were transformed into a grid with a resolution of 20 meters and adjusted to correspond spatially overlapping of agricultural land under the EC criteria and LPIS. For each criterion was created by a separate binary raster where:

- value of 0 means – no met the criterion
- value of 1 means – met the criterion.

By spatial combination of individual criteria raster in each municipality there was obtained information about the unique spatial combinations of raster values. All combinations (area) that have at least one criterion for a value of 1 should be marked as valid at the level of aggregate criteria. One example is shown on the Figure 5. Input binary data are: number of municipality, the municipality name and a list of the ANC criteria. Relative area of the municipality (%), in which the criterion applies is identified by the field name KUMUL, SVAH, DRENAZ, PIESOK, IL, SKELET, HLBKA and SALINITA. Relative area of the municipality (%), in which the criterion is no valid is marked as field name identifying the criteria and the suffix "NO" to underscore (KUMUL_NIE, SVAH_NIE. *etc.*). Calculation of the final table of the individual criteria and aggregate output ensures complete consistency of output when the presence of any number of criteria at some point is counted only once.

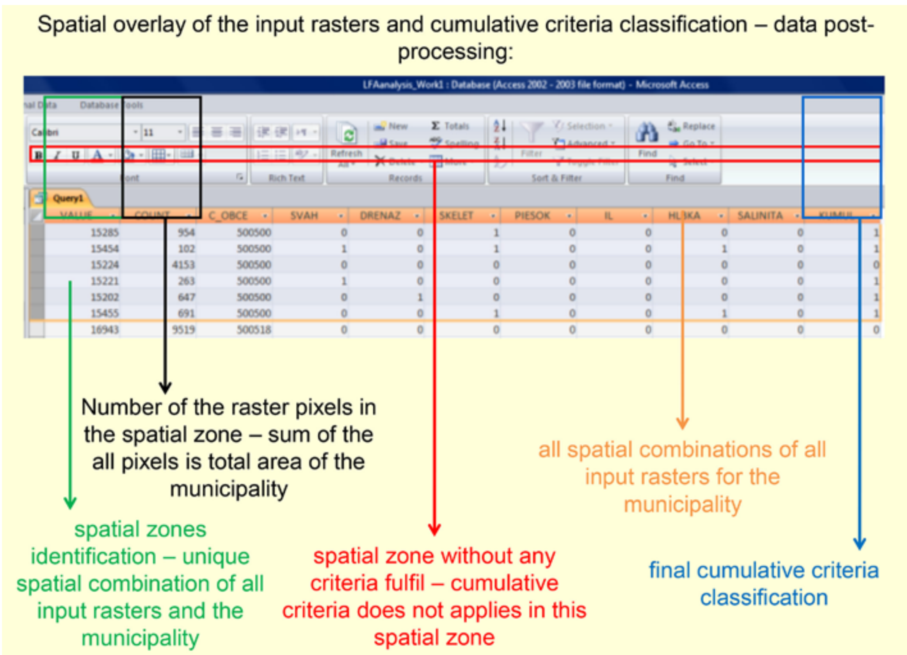

Figure 5 Database of input binary data

On the Figure 6 is shown a spatial occurrence of individual criteria applied across the pixel display of several municipalities.

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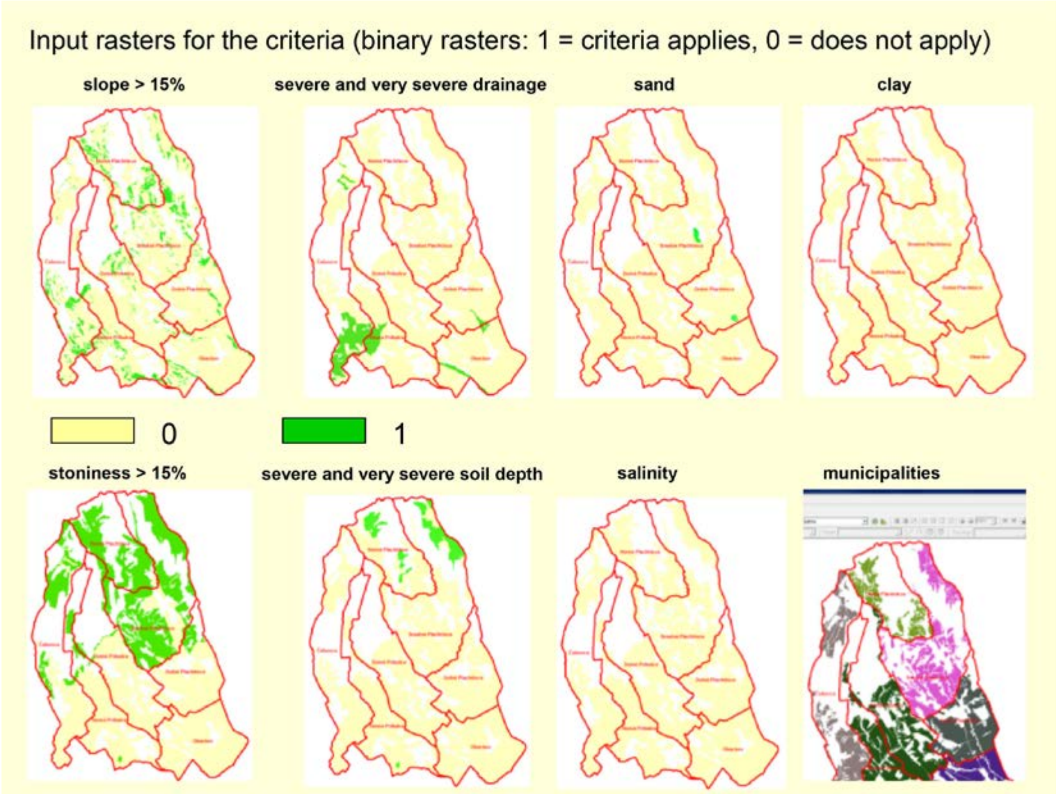

Figure 6 An example of municipality areas with binary database input of criteria applied in Slovakia

By simple proportion of the pixel's frequency labeled 1 to the total numbers of pixels representing the natural constrains in the municipality was calculated the percentage of area with at least one valid criterion. The result of the calculation is a unique combination of raster for each municipality (Fig. 6). The final binary raster (Fig. 8) represents the aggregate criterion with 60% percentage representation of binary raster-based aggregate values of natural constrains.

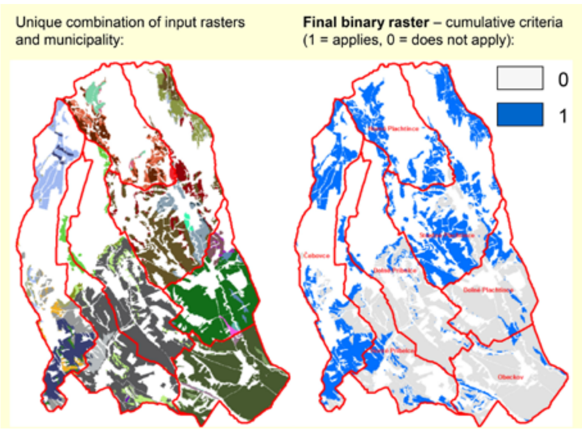

Figure 7 Final binary raster for individual municipalities

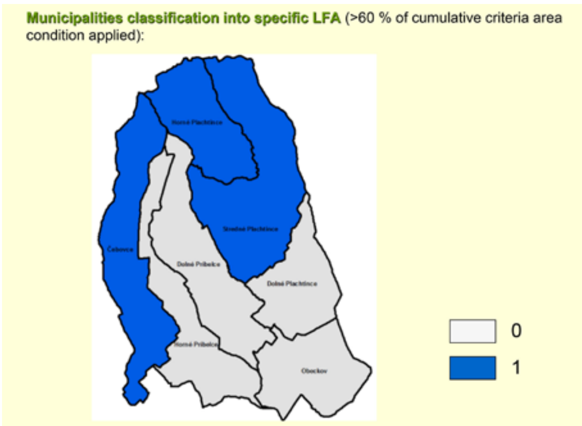

Figure 8 Delimitation of municipalities according to aggregate criterion 0 – non-delimited, 1– delimited

As components of the BKA criterion are the following components: poor chemical properties (salinity, sodicity), unfavourable soil texture – heavy clay soils, unfavourable soil texture – organic soils. These criteria have little extent, therefore, cannot be considered as the main criterion.

Criterion application: poor chemical properties (salinity, sodicity) (Van Orshoven, Terres, Tóth 2013)

Limits: the criterion means to have high content of salts or exchangeable sodium and excessive acidity in soil:

- Salinity: ≥ 4 dS per 1 m
- Sodicity: ≥ 6 percent exchangeable (ESP)
- Acidity of soils: pH ≤ 5,5 (in water)

To calculate the area of saline or sodification soils the system evaluated soil-ecological units (BPEJ) relating to the LPIS was processed. According diagnostics involved in the Morphogenetic soil classification system (MSCS 2000) for the Solonchaks are provided the following criteria:

- thickness >15 cm
- pH of the saturated soil paste < 8,4
- electrical conductivity at least in part horizon >15 dS per 1m
- content of soluble salts > 1% hm

For Solonetz is applied this diagnostics:

- thickness >15 cm
- by sodium exchangeable sorption complex saturation (ESP) > 15%
- pH in H_2O at least in some part of horizon > 8,4.

Diagnostic criteria of EC meet Solonetzs and Solonchks (MSU 96) – saline soils, as well as saline soils occurring in complexes of Phaeozems with Solonetzs (MSU 31), and complex of Gleyic Chernozems (Sodic) with Solonetzs (MSU 42). Correlation of saline soil types of the MKSP (2000) to the WRB (2006, 2007) is shown in the Table 10.

Table 10

A correlation of saline soils MSCS (2000) and WRB (2006, 2007)

MSU	Characteristics (MKSP 2000)	Characteristics (WRB 2006, 2007)
31	Ciernitza arable in complexes with Slanec arable (saline soils cover only 20 – 30% of area in form small scattered areas), moderately heavy, heavy or very heavy	Salic Phaeozems in complexes with Solonetz (arable) (typical saline soils cover only 20 – 30% the form of small scattered areas), in loamy or clayey texture or clays
42	Gleyic Chernozems arable in complexes with Slanec arable, (saline soils cover soils only 20 – 30% in form of small scattered areas), moderately heavy or heavy	Gleyic Chernozems (Sodic) in complexes with Solonetz (typical saline soils cover only 20 – 30% the form of small scattered areas), in loamy or clayey texture or clays
96	Slanisko arable and Slanec arable	Solonchaks and Solonetzs (arable)

Criterion application: unfavourable soil texture – heavy clay soils (Van Orshoven, Terres, Tóth 2013)

Limits: relatively high content of clay, silt, sand particles. Limits of fine earth texture are:

- texture of fine earth of top horizon (sand, silt, clay) is defined like:
  - silt % + (2 x clay %) ≤ 30%, OR
  - textural class of top horizon is very clayey (≥ 60% clay),
- textural class of top horizon clay, silty clay, sandy clay and vertic properties to 100 cm from the soil surface.

Clay soils are defined on the basis of textural class, which contains heavy clay (≥ 60% clay). Their occurrence is so negligible that it is only considered as part of the aggregate criterion.

Criterion application: unfavourable soil texture – organic soils (Van Orshoven, Terres, Tóth 2013)

Limits: Relatively high content of organic matter (wt. %). Limit organic matter content:

- proportion of organic matter ≥ 30 % at least in thickness 40 cm.

For the definition of organic soils n the BPEJ system there was required to evaluate diagnostic features

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characteristic for Morphogenetic soil classification system (MSCS 2000), and correlated to the WRB (2006, 2007). For organic soils in Slovakia diagnostic feature peat Ot horizon is characteristic – topsoil hydromorphic horizon developed by accumulation of organic plant residues without any marked mixture by mineral material, and having:
a) thickness > 50 cm, at Gleyic Histosol > 30 cm;
b) > 50 % matter of organic combustible substances.

These conditions meet main soil unit (MSU) in the BPEJ system encoded like:

95 Organozems – peat soils (Fibric Histosols in the WRB 2006, 2007).

Developed methodology for Slovakia was approved by JRG commission (EC) after presentation with EC representatives.

CONCLUSION

Slovak Republic meets the criterial values set out in Annex III of Regulation No.1305/2013 except for one and that is unfavourable stoniness in which Slovak Republic (due to insufficient database) defines areas with coarse material content with the limit ≥ 25% (vol.). For all biophysical criteria that Slovakia applied individually or as part of aggregate criterion were by JRC approved as methodology for classifying Areas with Natural Constrains after many consultations and discussions. All biophysical criteria including components as part of the criteria BKA were presented and tested in the official presentation with representatives of the EC JRC and 2 times – in Brussels (2010) and Štrbské Pleso (2011). Resulting Map of Areas with Natural Constrains serves as basis for farmer´s subsidies up to now (Sobocká *et al.* 2011). Mountains areas and areas with specific constrains which were assessed separately and are not subject of this study.

REFERENCES

Balkovič, J., Skalský, R., Nováková, M. (2010). Priestorový model distribúcie piesku a ílu v ornici poľnohospodárskych pôd Slovenska (Spatial model of the sand and clay distribution in topsoil of agricultural soils in Slovakia). In: Bujnovský, R. (ed.) *Vedecké práce Výskumného ústavu pôdoznalectva a ochrany pôdy* č. 32. Bratislava: VÚPOP, 2010, s. 5 – 13.

Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD). (2005). Available on: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32005R1698.

Čurlík, J., Šefčík, P. (1999). *Geochemický atlas Slovenskej republiky.* Časť V: Pôdy (Geochemical Atlas of the Slovak Republic. A part: Soils). Bratislava: MŽP SR a VÚPOP, 1999, ISBN 80-88833-14-0.

Džatko, M., Sobocká, J. (2009). *Príručka pre používanie máp pôdnoekologických jednotiek Inovovaná príručka pre bonitáciu a hodnotenie poľnohospodárskych pôd Slovenska*. (A handbook for using of land-evaluation unit's maps). Bratislava: VÚPOP Bratislava, 28 p. ISBN 978-80-89128-55-6 (in Slovak) .

Eliasson, A., Terres, J., Bamps, C., eds. (2007). *Common Biophysical Criteria for Defining Areas which are Less Favourable for Agriculture in Europe*. 2007. EUR 22735 EN. JRC37852.

FAO (2006). *Guidelines for soil description*. Fourth edition. Rome: Food and Agriculture Organization of the United Nations, 97 p.

Hraško, J., Linkeš, V., Šály, R., Šurina, B. (1993). *Pôdna mapa Slovenska 1:400 000*. (Soil Map of Slovakia in the scale 1:400,000). Bratislava: Výskumný ústav pôdnej úrodnosti 1993.

IUSS Working Group WRB (2006, 2007). World reference base for soil resources 2006. First update 2007. *World Soil Resources Reports* No. 103. Rome: Food and Agriculture Organization of the United Nations, 128 p.

Kobza, J., Barančíková, G., Čumová, L., Dodok, R., Hrivňáková, K., Makovníková, J., Bezáková, Z., Pálka, B., Pavlenda, P., Schlosserová, J., Styk, J., Širáň, M., Tóthová, G. (2009). *Monitoring pôd Slovenskej republiky. Súčasný stav a vývoj monitorovaných vlastností pôd ako podklad k ich ochrane* *a ďalšiemu využívaniu.* (Soil monitoring in Slovak Republic. Present state and development of monitored soils as the base to their protection and next land use). VÚPOP Bratislava, 200 s. ISBN 978-80-89128-54-9.

Kobza, J., Barančíková, G., Dodok, R., Makovníková, J., Pálka, B., Styk, J. Širáň, M. (2019). *Monitoring pôd SR. Súčasný stav a vývoj monitorovaných vlastností pôd ako podklad k ich ochrane a ďalšiemu využívaniu (2013–2017).* Soil monitoring in the Slovak Republic. Current state and development of monitored soil properties as a basis for their protection and further use (2013–2017. NPPC – VÚPOP Bratislava, 2019, 252 s. ISBN 978-80-8163-033-0.

Linkeš, V., Pestún, V., Džatko, M. (1996). *Príručka pre používanie máp bonitovaných pôdno-ekologických jednotiek. Príručka pre bonitáciu poľnohospodárskych pôd.* (A handbook for using of land-evaluation unit's maps. Guidelines for evaluation of agricultural soils.). Third revised version, VÚPÚ Bratislava, 104s. ISBN 80-85361-19-1.

Němeček, J., Damaška, J., Hraško, J., Bedrna, Z., Zuska, V., Tomášek, M., Kalenda, M. (1967). *Komplexní průzkum zemědělských půd ČSSR – souborná metodika, 1. díl.* (Agricultural soil survey of CSSR – soil survey guide: Part 1). Praha: Min. zem. a výž., 246 pp. (In Czech with English, German, and Russian summary).

Němeček, J., Macků, J., Vokoun, J., Vavříček, D., Novák, P. (2001). *Taxonomický klasifikační systém půd České republiky.* (The Czech Taxonomic Soil Classification System) Praha: ČZU, 2001, 78 s., ISBN 80-238-8061-6.

Pásztor, L., Szabó, J., Bakacsi, Z. (2010). Application of the Digital Kreybig Soil Information System for the delineation of naturally handicapped areas in Hungary. Agrokémia és Talajtan 59(1). DOI: 10.1556/Agrokem.59.2010.1.6.

Saksa, M., Skalský, R., Čurdová, K., Pivarčeková, E., Bartošovičová, I. (2009). *Súčasný stav budovania Georeferencovanej databázy poľnohospodárskych pôd Slovenska* (Current state of building the Georeferenced database of agricultural soils in Slovakia). In *Vedecké práce*, roč. 31. Bratislava: VÚPOP, 2009, s. 144–150.

Skalský, R. (2005). The georeferenced database of agricultural soils of Slovakia. In *Vedecké práce*, roč. 27. Bratislava: VÚPOP, 2005, s. 97–110.

Skalský, R., Balkovič, J. (2002). Digital Database of Selected Soil Profiles of Complex Soil Survey of Slovakia (KPP-DB). In *Vedecké práce*, roč. 25. Bratislava: VÚPOP, 2002, s. 129–140.

Sobocká, J. Skalský, R., Molčanová, J., Brodová, M. (2011). *Vymedzenie znevýhodnen*ých *oblastí v Slovenskej republike v kontexte navrhovaných kritérií Európskej komisie pre ostatné znevýhodnené oblasti pre programovacie obdobie 2014 – 2020* (správa za rok 2011). (Delimitation of LFA in Slovak Republic in the context of redefined EC criteria of other less favourable areas for the Rural Development Programme 2014 – 2020 (Report 2011). MPRV SR, VÚPOP Bratislava, 60 s.

Sobocká, J. Skalský, R. (2013). *Definitívny návrh jednotlivých kategórií LFA, podmienok a výšky platieb pre Program rozvoja vidieka SR 2014 – 2020.* (Definitive proposal of individual LFA categories, conditions and amount of payments for the Rural Development Program of the Slovak Republic 2014 – 2020, Final report). Záverečná správa VÚPOP Bratislava, 61 s.

Sobocká, J., Skalský, R., Saksa, M., Pivarčeková, E., Čurdová, K. (2013). *Testing of methods and procedures used for redefinition of less favourable areas in Slovakia*. Správa pre JRC Ispra. VÚPOP Bratislava, 30 s.

Sobocká, J., Saksa, M., Skalský, R., Houšková, B., Pivarčeková, E., Čurdová, K., Hanisko, Ľ., Bartošovičová, I. (2013). *Digitalizácia databázy komplexného prieskumu poľnohospodárskych pôd Slovenska ako podklad pre doriešenie kriteriálneho hodnotenia LFA na úrovni obce.* (Digitization of the database of a comprehensive survey of agricultural land in Slovakia as a basis for solving the criterion evaluation of LFA at the municipal level, Final Report). Záverečná správa, VÚPOP Bratislava, 31 s.

Sobocká, J. Skalský, R. (2014). *Dopracovanie vymedzenia znevýhodnených oblasti (špecifické a ostatné) v SR v kontexte zmeny podmienok navrhnutých kritérií Európskou komisiou.* (Completion of the definition of less favourable areas (specific and other) in the Slovak Republic in the context of changing the criteria conditions proposed by the European Commission, Final Report). Záverečná správa VÚPOP Bratislava, 33 s.

Soil Survey Division Staff. (1993). Soil Survey Manual. *United Department of Agriculture Handbook* No. 18., USDA, Washington DC. 437p.

Takáč, J., Nováková, M., Skalský, R., Sobocká, J. (2010). Identifikácia sucha na Slovensku s použitím klimatických kritérií (Drought identification in Slovakia using climate criteria). In *Vedecké práce VUPOP*, č. 32, Bratislava. ISBN 978-80-89128-82-2. 88 – 100.

Takáč, J. (2015). *Sucho v poľnohospodárskej krajine* (Drought in agricultural land). NPPC – VÚPOP Bratislava, 69 s. ISBN 978-80-8163-012-5.

Van Orshoven, J., Terres, J-M., Eliasson A. (eds) (2008). *Common bio-physical criteria to define natural constraints for agriculture in Europe*. EK – JRC, IES, 61 pp. LB – NA23412 – EN – C.

Van Orshoven, J., Terres, J-M., Tóth, T. (2013). *Updated common bio-physical criteria to define natural constraints for agriculture in Europe. Definition and scientific justification for the common biophysical criteria*. JRC Scientific and Technical Reports. Luxembourg: Publications Office of the European Union, 2013.

VÚPOP, SPS (2000). *Morfogenetický klasifikačný systém pôd Slovenska Bazálna referenčná taxonómia.* (Morphogenetic Soil Classification System of Slovakia, Basic Reference Taxonomy). Bratislava, 76 p. ISBN 80-85361-70-1.

Vopravil, J., Novotný, I., Pírková, I., Khel, T., Vrabcová T. (2010). *Redefinice LFA Metodický postup vymezování na základě přírodních kritérií.* (Re-definition of the LFA. Methodology of delineation on the natural criteria base). Praha: Výzkumný ústav meliorací a ochrany půdy Praha, 2010. ISBN 978-80-87361-03-0.

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