Creating GIS on the Pilot Area of the Litoměřice District – From Soil Survey to International Information Systems

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Abstract: The procedure of processing and utilising the soil information entering the SOTER system is tested on the pilot area of the Litoměřice district. The reliability of the archive data is examined, the archive data being updated by a new soil survey, modern (geo)statistical methods, and pedotransfer rules. Using the SOTER methodology, a soil map of the district with the scale of 1:50 000 has been developed. Proposals for the adjustments to the currently valid soil classification system are processed.

Keywords: archive soil data; soil survey; (geo)statistical methods and pedotransfer rules; soil GIS; SOTER

The last few decades have seen a significant change in the perceiving pedology, and thereby in the perceiving soil survey, especially due to the knowledge development in individual scientific disciplines interlinked with pedology, and also to gradual monitoring of interdisciplinary links. In the context of creating soil units, various conceptions of present-day pedology can be defined; soil classifications in these conceptions develop from the so called 'central concept' towards fuzzy methods, and area (or region) mapping analogically uses pedons, polypedons and associations. The SOTER project (e.g. Nachtergaele 2003) is not a soil GIS only any more. It affects a range of natural sciences (e.g. climatology and botany) and prospectively also a lot of other disciplines, perhaps even economic ones. It depends on the pace of IT development in general and on pedologists' ability to keep up with the development (e.g. Finke *et al.* 2001; Němeček & Kozák 2003).

The proposed method of processing and utilising the soil data is tested on a varied and complex terrain of the Litoměřice district. The formation of the district soils was influenced by favourable climatic conditions (a third of the district is occupied by a warm and two thirds by mildly warm areas), by the geological structure of the region, to which almost all geological periods have contributed, from the oldest metamorphic rocks to the most recent Holocene alluvia, as well as by hydrological conditions, which correspond to the region geological structure, terrain relief and climatic conditions.

For the purpose of SOTER, the geomorphology of the Litoměřice district is currently divided into 8 regions: plateaus, flat lowlands, dissected lowlands, flat highlands, dissected highlands, dissected mountains, flat higher lowlands, and dissected higher lowlands.

The soils of the Litoměřice district are, according to the currently valid taxonomic system, represented as follows: Chernosols (formerly Chernozems, Flood-plain soils) 37.76%, Cambisols (Brownsoils) 16.29%, Leptosols and Regosols (Rendzinas, Sod soils) 24.63%, Luvisols (Hnedozems, Illimerised soils) 10.94%, Fluvisols (Alluvial soils) 8.95%, Stagnosols (Stagnic soils) 0.82%, and Gleysols (Gleyic and Sod-gleyic soils) 0.60% of agricultural land.

MATERIAL AND METHODS

The pilot area of the Litoměřice district, delimited as in the General agricultural land survey, serves to test the process of creation, processing, and utilisation of soil information, which enters the SOTER system. The soil data are classified by a combination of the soil classification system and (geo)statistical methods in a single process, from obtaining the data in the field research up to their incorporation into the international GIS. It is demonstrated that both approaches need to be applied jointly and not separately, unlike in common practice. The thesis uses all available archive data from the General agricultural land survey of the Czech Republic (hereinafter referred to as KPZP) for the geomorphologically and, as to the soil composition complex district of Litoměřice, particularly 1:50 000 and 1:5 000 soil maps, 1:50 000 cartograms of the parent materials and particle size, and the information on the primary, selected, and special test pits from the KPZP Accompanying Report and from the field soil records.

ArcView (version 3.1) was used as the basic GIS software. The values of clay particles content (zrn1), organic mater content (hum), active soil reaction (pH_{H2O}), and potential exchangeable soil reaction (pH_{KCl}) were examined by classical statistical methods in the programm Statgraphics (version 4.0). The same properties were analyzed using two types of software designed for geostatistical data processing – GS^+ Geostatistics for the Environmental Sciences (version 5.1) and Surfer (version 8.0).

The digitisation of KPZP data, the creation of primary thematic layers of GIS KPZP – agricultural areas (Figure 1), and the network of test pits (Figure 2) as well as the interconnection of the graphic and descriptive parts of the KPZP database were the first steps in the formation of a new procedure for determining soil and stand-soil units, which facilitates their application to any Czech, as well as international, soil information system, and especially to the SOTER system (Soil and Terrain Digital Database).

The method of processing and using the soil information entering the SOTER system was proposed, elaborated, and tested in the following steps:

– Collection of available data on the basic and selected test pits in digital database (Sládková & Kozák 2006).
– Updating the data by expansion of soil types by terrain reconnaissance and by new test pits, and proposing adjustments to the valid Taxonomic Classification System of Soils of the CR (Němeček *et al.* 2001).
– Conversion of KPZP genetic-agronomic classification (GAK KPZP) into the Taxonomic Classification System of Soils of the CR (TKSP CR) and into the World Reference Base for Soil Resources (WRB).
– (Geo)statistical data processing.

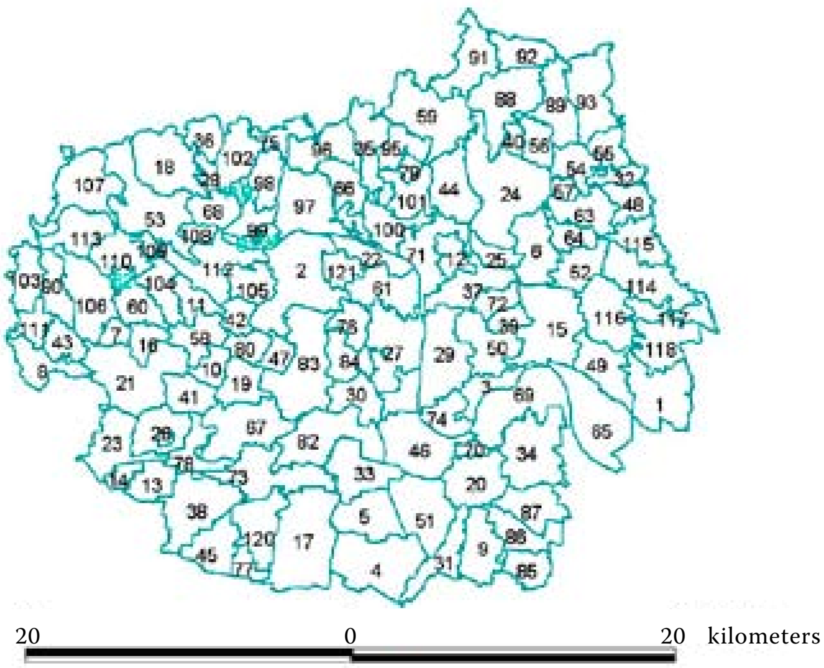


Figure 1. Agricultural areas overview of the Litoměřice district after complete digitalisation of archive groundwork papers (encoding)

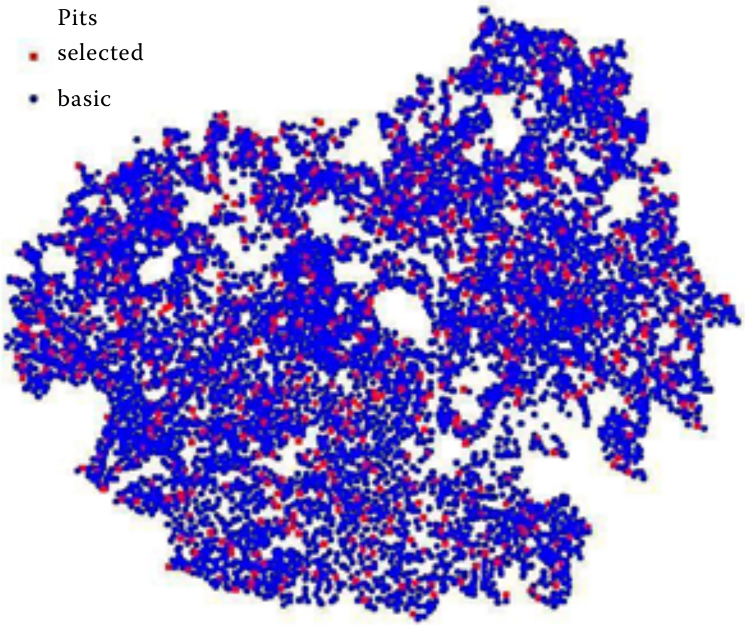


Figure 2. The network of dug soil pits of the Litoměřice district

– Application of pedotransfer rules to complete the data from the soil survey and making the characteristics of diagnostic horizons more accurate.
– Creation of SOTER soil map of the Litoměřice district with the scale of 1:50 000 and a section of the SOTER soil map with the scale of 1:5 000. The creation of SOTER soil maps with middle and detailed scales is essential if SOTER is to serve as a tool for the soil survey. The localisation of test pits by combining with geomorphology will e.g. ensure that the map layers and sheets are in accordance when recording new test pits and drawing the updated soil areas.

RESULTS AND DISCUSSION

The results of laboratory analyses from the new soil survey already have been published, including corresponding proposals for the adjustments to the valid soil classification system (Sládková 2008a, 2009). Examples of conversions have also been published by Sládková (2008c, 2009). The extent of laboratory analyses is illustrated in Table 1, using the examples of test pits No. 6, 8, and 9.

The classification of the data according to the diagnostic horizons of the above-mentioned soil classification systems (the original, currently valid, and international systems) was followed by a primary evaluation using classical statistical methods and geostatistical methods. Soil classification systems, especially GAK KPZP, used as a default system, demonstrated a good quality of the data classification. As can be seen from the normality distribution graphs, even small sets meet the basic statistical requirements.

Following the adjustment to the input data from the values which in the preceding step had met all statistical requirements, certain physical soil characteristics were calculated using pedotransfer rules in order to specify TKSP CR and complete the soil survey data (Sládková & Kozák 2008).

The data acquired from in-situ measurement were classified using soil classification systems and further processed using the methods of classical as well as spatial statistics. The examined data, resulting mostly from KPZP, proved their reliability. A set of 49 test pits, selected and tested for the purposes of the KPZP Accompanying Report for Litoměřice district, demonstrated statistical results of a comparable quality as the collection of all the data from the digital KPZP Litoměřice district database.

The tests carried out on Gley modal to check if the properties calculated by pedotransfer rules correspond to the defined properties of diagnostic horizons, on which the input data were based, admit errors in the definitions of the diagnostic horizons studied. In order to reach the final conclusion concerning the suitability of the definitions, more data need to be evaluated – the data from

Table 1. Results of laboratory analysis concerning soil pits from the soil survey of the Litoměřice district in 2006

		Pit No. 6		Pit No. 8		Pit No. 9	
		hor. Apk	hor. Crk	hor. Apk	hor. Ck	hor. Apk`	hor. Ck
Soil properties and characteristics	Clay < 0.001 mm (%)	20.50	25.40	37.10	36.00	28.70	39.10
	< 0.002 mm (%)	25.20	41.20	44.50	46.20	35.50	49.60
	Part. size I < 0.01 mm (%)	36.50	68.60	60.00	68.50	48.10	71.60
	< 0.02 mm (%)	42.20	76.10	69.30	75.50	58.60	78.70
	< 0.05 mm (%)	51.20	84.70	81.50	85.80	73.90	86.20
	Part. size II 0.01–0.05 mm (%)	14.70	16.10	21.40	17.40	25.80	14.60
	Part. size III 0.05–0.25 mm (%)	22.80	9.30	10.40	7.40	11.70	6.70
	Part. size IV 0.25–2 mm (%)	26.10	6.00	8.10	6.80	14.40	7.00
	pH active (–)	7.74	8.10	7.78	8.13	7.35	8.04
	pH potential exchangeable (–)	7.48	7.80	7.36	7.50	7.02	7.41
	Carbonates (%)	14.00	48.00	6.80	30.00	0.30	27.00
	Cox (%)	1.26	0.34	2.14	0.28	1.66	0.34
	θ_{mom} (w. %.)	–	–	22.14	–	21.23	–
	θ_{mom} (% vol.)	–	–	34.98	–	26.80	–
	θ_{MKK} (% vol.)	–	–	31.40	–	34.25	–
	ρ_z (g/cm^3)	–	–	2.65	–	2.67	–
	$\rho_{d\ red}$ (g/cm^3)	–	–	1.58	–	1.26	–
	P (% vol.)	–	–	40.29	–	52.76	–
	Vz (% vol.)	–	–	5.31	–	25.96	–
	K_{MKKVZ} (% vol.)	–	–	8.89	–	18.51	–
	θ_{ns} (% vol.)	–	–	35.61	–	48.33	–
	θ_{BV} (% vol.)	–	–	20.80	–	16.2	–
Potential (cmol/kg)	CEC	14.66	10.27	30.43	18.10	25.88	20.34
	S	18.34	18.02	35.90	26.13	28.42	28.32
	K	1.07	0.88	1.46	0.70	0.96	0.60
	Na	0.59	0.62	0.65	0.64	0.59	0,63
	Mg	0.79	0.66	2.94	1.38	1.98	2.68
	Ca	15.80	15.79	30.82	23.35	24.84	24.30
	Al	0.09	0.07	0.03	0.06	0.05	0.11
Efficient (cmol/kg)	ECEC	15.55	10.77	31.65	22.03	26.29	22.84
	S	19.66	15.14	35.93	26.96	30.75	28.11
	K	1.17	0.83	1.48	0.73	1.01	0.61
	Na	0.65	0.62	0.68	0.66	0.67	0.66
	Mg	0.87	0.78	3.09	1.41	2.16	2.69
	Ca	16.91	12.83	30.63	24.07	26.86	24.09
	Al	0.06	0.08	0.05	0.09	0.05	0.06

Potential – extract of 0.01M $BaCl_2$ buffered by TEA to pH 8.1; efficient – extract of not buffered 0.01M $BaCl_2$

Soil samples were elaborated in the Central laboratories of the Research Institute for Soil and Water Conservation in Prague

Table 2. Statistical characteristics for sets of clay size particle amount and organic matter content (in %)

	zrn1_ ra_1	zrn1_ ra_2	zrn1_ ra_3	zrn1_ ra_4	hum_ ra_1	hum_ ra_2	hum_ ra_3	hum_ ra_4
Count	9	53	10	15	9	53	10	15
Arithmetic average	45.60	54.16	27.21	31.61	2.67	3.00	1.54	1.70
Median	48.30	55.30	28.50	30.10	2.47	3.00	1.51	1.74
Variance	219.34	164.89	87.65	158.24	0.44	0.54	0.08	0.12
Standard deviation	14.81	12.84	9.36	12.58	0.66	0.74	0.28	0.34
Minimum	27.80	19.20	16.50	13.90	2.00	1.10	1.11	0.89
Maximum	64.00	78.90	43.30	63.10	3.67	4.34	1.93	2.26
Range	36.20	59.70	26.80	49.20	1.67	3.24	0.82	1.37
Standardised kurtosis	–0.05	–1.33	0.34	1.97	0.86	–0.12	0.05	–1.28
Standardised skewness	–1.28	0.81	–0.72	1.36	–0.70	–0.37	–0.62	0.93

Table 3. Statistical characteristics for sets of clay size particle amount and organic matter content (in %) (see Figures 3–10)

	zrn1_ra_13	zrn1_ra_24	zrn1_ra_1324	hum_ra_13	hum_ra_24	hum_ra_1324
Count	19	68	87	19	68	87
Arithmetic average	35.92	49.19	46.29	2.07	2.71	2.57
Median	31.50	49.85	47.50	1.93	2.69	2.48
Variance	230.31	249.83	273.24	0.57	0.74	0.77
Standard deviation	15.18	15.81	16.53	0.75	0.86	0.88
Minimum	16.50	13.90	13.90	1.11	0.89	0.89
Maximum	64.00	78.90	78.90	3.67	4.34	4.34
Range	47.50	65.00	65.00	2.56	3.45	3.45
Standardised kurtosis	1.03	–1.07	–0.52	1.75	0.30	0.92
Standardised skewness	–0.64	–1.00	–1.74	0.26	–1.20	–1.53

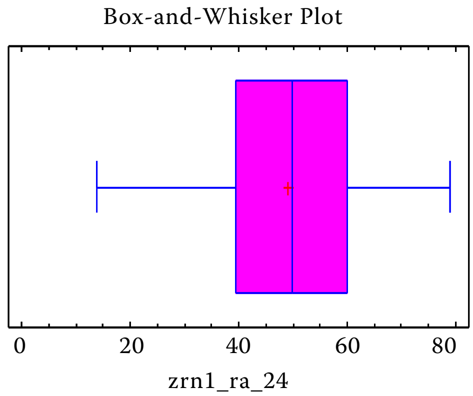


Figure 3. Exploratory analysis of the set zrn1_ra_24

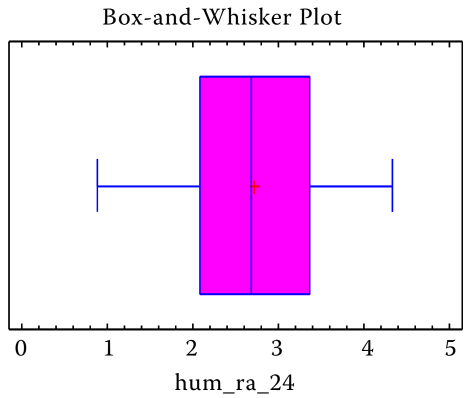


Figure 4. Exploratory analysis of the set hum_ra_24

Table 4. Principal parameters of correlation and regression for some models

Set	Multiplicative		Exponential		Linear	
	I , r < 0, 1 >	I^2, r^2 (%)	I , r < 0, 1 >	I^2, r^2 (%)	I , r < 0, 1 >	I^2, r^2 (%)
ra_1	0.541	29.30	0.545	29.71	0.575	33.02
ra_2	0.440	19.34	0.390	15.17	0.379	14.37
ra_3	0.860	73.87	0.855	73.10	0.866	75.07
ra_4	0.407	16.53	0.381	14.54	0.389	15.12
ra_13	0.817	66.73	0.803	64.53	0.794	63.08
ra_24	0.663	43.93	0.630	39.66	0.607	36.80
ra_1324	0.729	53.08	0.700	48.93	0.677	45.83

I – correlation index; I^2 – index of determination; r – correlation coefficient; r^2 – coefficient of determination

Explanatory notes to Tables 2–4

Diagnostic horizons of classification systems:

GAK KPZP – OrH(ca), OrHca, Orh(ca), Orhca; TKSP CR – Apk`, Apk; WRB – A

zrn1 – clay size particle (d < 0.01 mm) amount (%) – first size particle category after classification scale by Novák

hum – organic matter content (%) detected by modified Tjurin method

zrn1_ra_1, hum_ra_1	all horizons OrH(ca) from pits of Rendzina typic (GAK KPZP), i.e. Rendzina modal (TKSP CR) and Rendzic Leptosol (WRB), on the district	(9)
zrn1_ra_2, hum_ra_2	all horizons OrHca from pits of Rendzina typic on the district	(53)
zrn1_ra_3, hum_ra_3	all horizons Orh(ca) from pits of Rendzina typic on the district	(10)
zrn1_ra_4, hum_ra_4	all horizons Orhca from pits of Rendzina typic on the district	(15)
zrn1_ra_13, hum_ra_13	all horizons OrH(ca) and Orh(ca) (i.e. Apk`) from pits of Rendzina typic on the district	(19)
zrn1_ra_24, hum_ra_24	all horizons OrHca and Orhca (i.e. Apk) from pits of Rendzina typic on the district	(68)
zrn1_ra_1324, hum_ra_1324	all horizons OrH(ca), Orh(ca), OrHca and Orhca (i.e. A) from pits of Rendzina typic on the district	(87)

End figures in the sets names indicate the horizon numbers in the database, the figures in the brackets indicate the numbers of horizons applied in statistical calculations

the test pits of the same soil types in other districts. Although the calculations of pedotransfer rules for Rendzina typic (GAK KPZP) – Rendzic Leptosol (WRB) suggest that the selection of the test pits for the Accompanying Report accurately characterises the set of all selected test pits, the soil survey and the study of available maps show that in the Litoměřice district, the decisions according to which basic test pit will at the same time serve as a selected test pit, were not exactly right.

The pedologic-classical statistics was used to evaluate the horizons of all subtypes of Chernozems and Rendzinas according to GAK KPZP (which take up a major part of the district) as for the dependency of the organic mater content on the amount of clay particles. All models proved that the system parameters had been well set and that the soils had been correctly defined at the stage of field data processing. An example of the procedure and the results obtained when using the statistical data processing of Rendzinas are illustrated in Tables 2–4, Figures 3–10.

It was proved that at a later stage of processing, the sets whose exploration analysis reveals outlying values often demonstrate a stronger correlation than the sets lacking such outlying values. Generalising the properties for the classification into individual soil horizons improves the primary descriptive characteristics of individual sets while the intensity of correlation between the individual sets is comparable or even higher. The same consequences (both of them or at least one of them) are shown also by combining the same diagnostic horizons from different soil types and subtypes

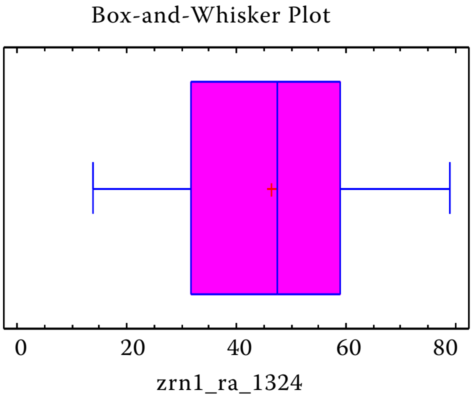


Figure 5. Exploratory analysis of the set zrn1_ra_1324

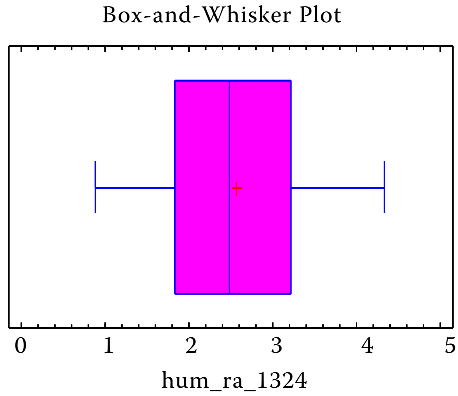


Figure 6. Exploratory analysis of the set hum_ra_1324

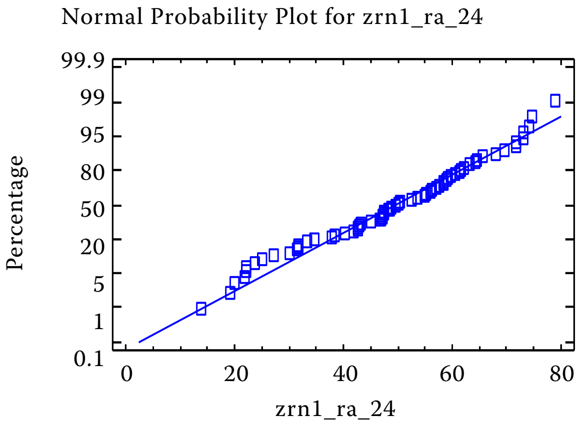


Figure 7. Normality of the set zrn1_ra_24

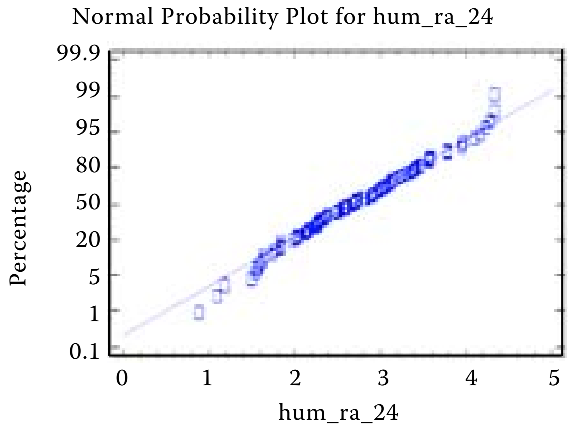


Figure 8. Normality of the set hum_ra_24

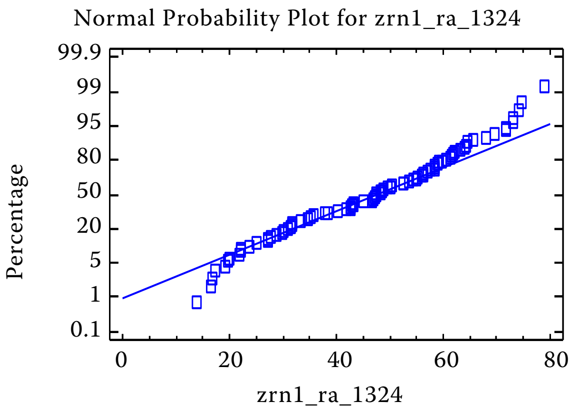


Figure 9. Normality of the set zrn1_ra_1324

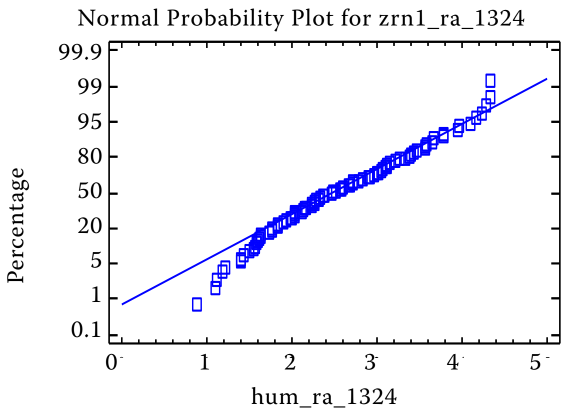
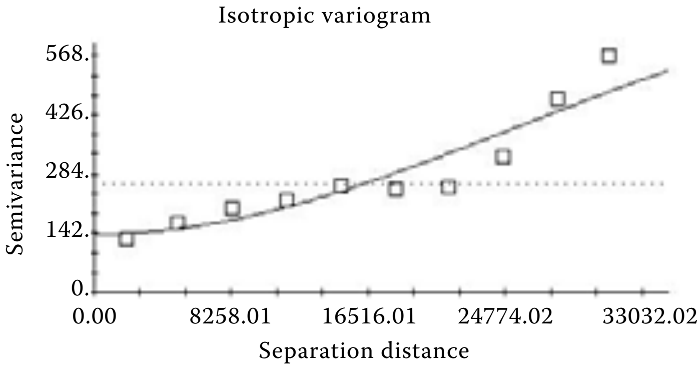


Figure 10. Normality of the set hum_ra_1324

into a single set. An exception to the rule is the situation where an attached set contains one or two values which, after being combined, may act as extremes (Sládková & Němeček 2006).

Geostatistics was used to process the data for the topsoil horizons of Rendzina typic, separately for the basic and the selected test pits and, so as to be compared with classical statistics, also for the same horizons of Rendzina typic in the district and all topsoil horizons of the selected test pits of Rendzina typic with unabridged data, including their locations. The variograms for the values of clay particles and organic mater contents, active soil reaction and potential exchangeable soil reac-



Gausian model (Co = 140.0000; Co + C = 790.9000; Ao = 35950.00; r^2 = 0.871; RSS = 21955)

Figure 11. Clay size particle amount – basic pits (isotropic variogram)

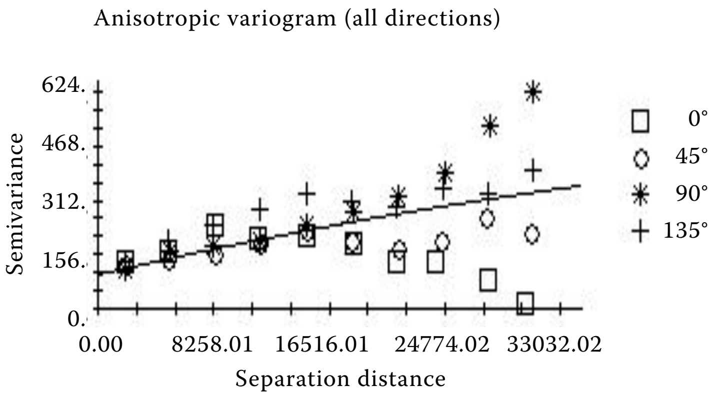
tion and also mutual variograms of clay particles and organic mater contents and mutual variograms of soil reactions showed a relatively low spatial dependency (Sládková 2007, 2008b).

Following the adjustment to the soil conversions and statistical processing of the KPZP data, the polygons of the 1:50 000 soil map of the Litoměřice district were reclassified from GAK KPZP into TKSP CR (Figure 1 and 2 in Sládková 2009) and, by assigning parent materials from the soil forms map, main soil forms were created; after the inclusion of geomorphology, conversion of parent materials into grouped SOTER parent materials and by assigning generalised soils, dominant SOTER units were created. Based on these three layers (geomorphology, soils, parent materials), the following maps were created: 1:50 000 SOTER soil map of the Litoměřice district (Figure 13) and a section of the 1:5 000 SOTER soil map (Figure 2 in Sládková 2008a).

Classical statistical processing of the KPZP digital database data of the Litoměřice district and the subsequent geostatistical data processing – examples:

Selected test pits sets were used to process the data on the dependency of organic mater content (hum) on clay particles content – d < 0.01 mm (zrn1) for the horizons of individual soil subtypes of Rendzina typic (according to GAK KPZP). Tables 2 and 4 illustrate GAK KPZP horizons, Tables 3 and 4 illustrate TKSP CR and WRB horizons. The results of the exploratory analysis and examination of the distribution normality of all OrHca and Orhca horizons (i.e. Apk) 68 Rendzina typic test pits in the district and all OrH(ca), Orh (ca), OrHca, Orhca horizons (i.e. A) 87 Rendzina typic test pits in the district are shown in Figures 3–10.

Primary descriptive characteristics are described in Tables 2 and 3. What follows is an exploratory analysis (Figures 3–6), examination of the distribution normality (Figures 7–10) and under the terms of simple linear and non-linear correlation and regression, the principal parameters



Exponential model (Co = 97.8000; Co + C = 721.7670; A1 = 65080.00; A2 = 65080.00; r^2 = 0.6981; RSS = 423882)

Figure 12. Clay size particle amount – basic pits (anisotropic variogram)

of correlation and regression for some models (Table 4).

The models (Table 4) indicate medium-strength dependency of organic mater content on the amount of clay particles, with the exception of Orhca horizons of test pits of Rendzina typic, which demonstrates weak dependency. From all the models applied here, the most appropriate seems to be the multiplicative model, and in general most frequently the linear model. When selecting a model, it is essential to consider also the presence of unusual residues and influential points as well as the difficulty of particular model interpretation.

Isotropic variogram and anisotropic variogram for variable $zrn1_z$ (values of clay particles content of all basic test pits in the Litoměřice district) are illustrated in Figures 11 and 12.

Nowadays, when creating GIS on soils in the CR and constructing middle- and detail-scale SOTER maps, it is necessary to use the archive data in order to resolve numerous problems, such as:

– To process digitally more data in the form applicable to GIS.
– To finish a convertor between GAK KPZP and TKSP CR (for Rendzinas in Sládková 2009), using GIS of other districts, and to propose further adjustments to TKSP CR.

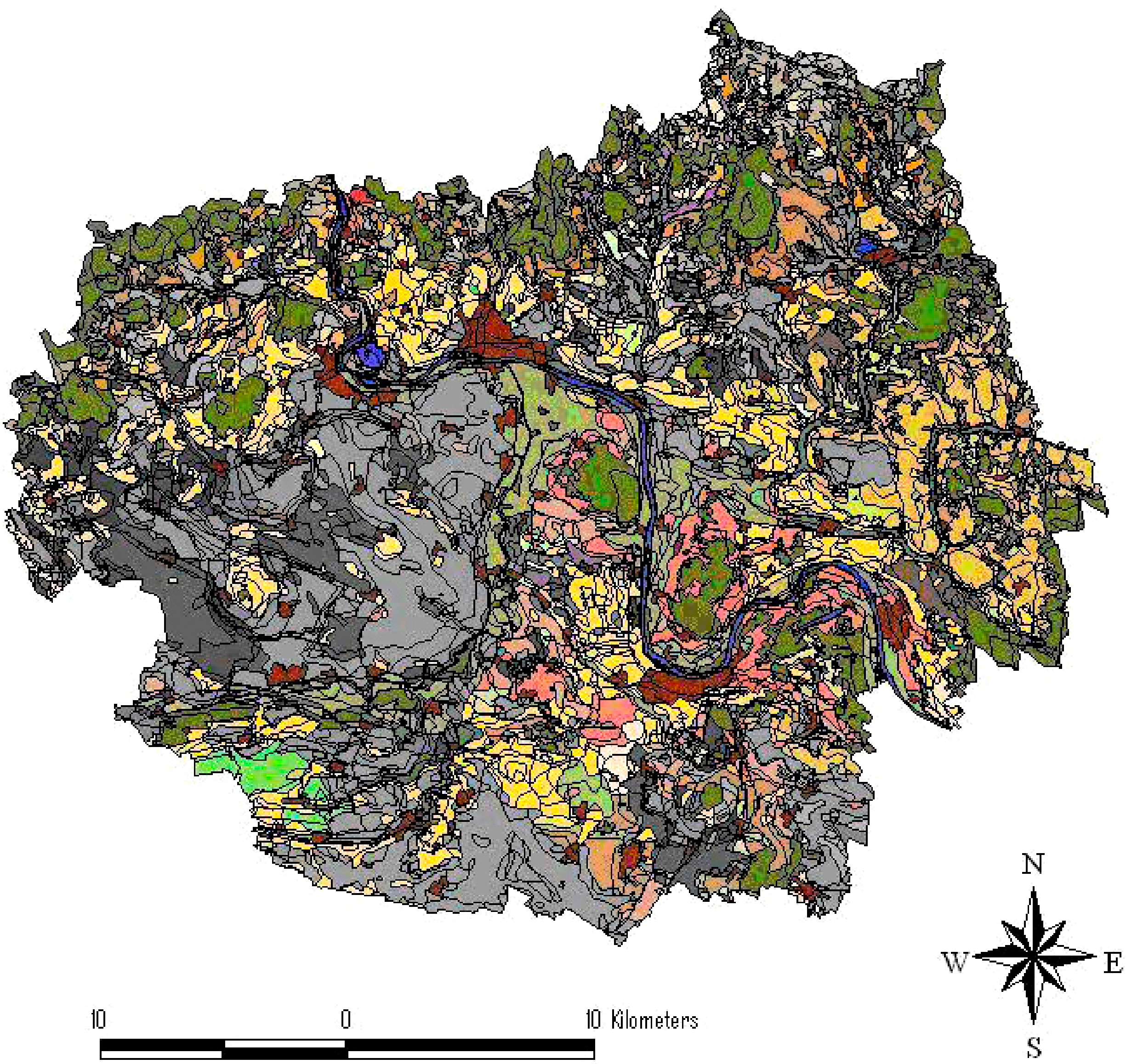
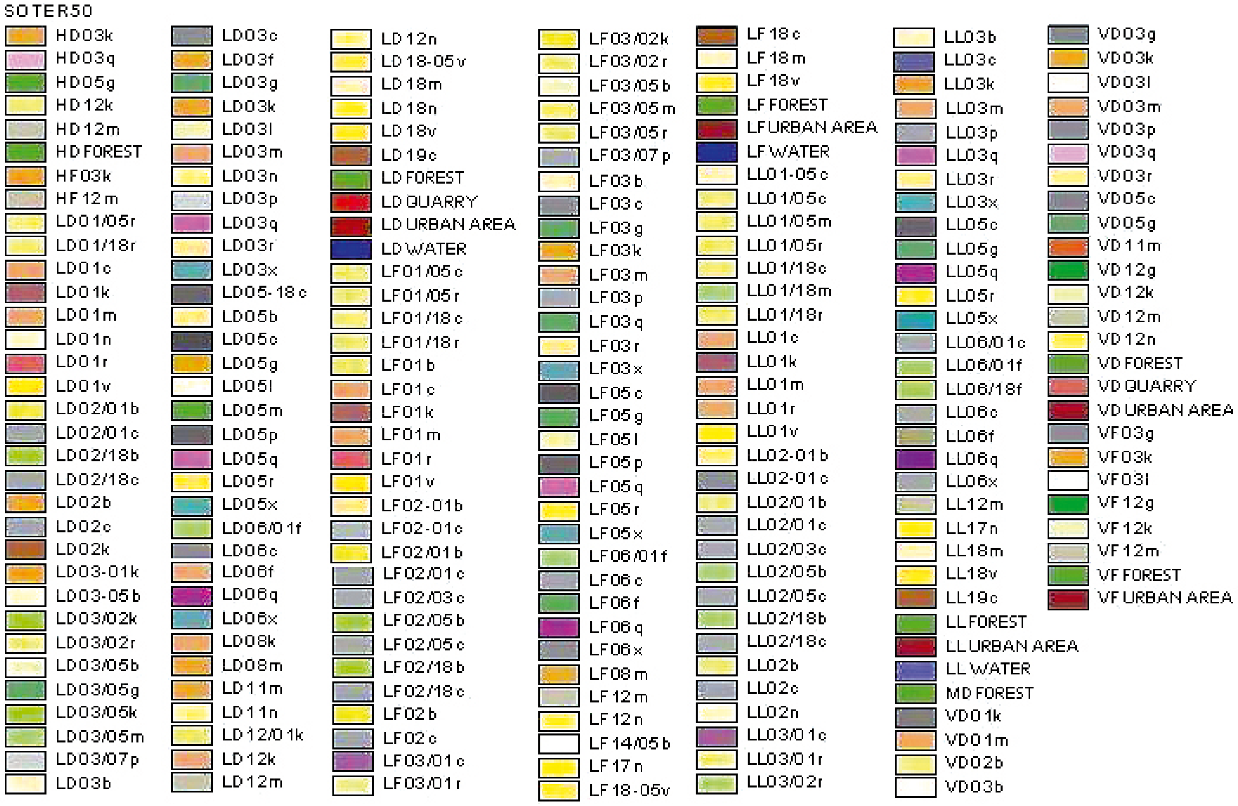


Figure 13. The SOTER soil map at the scale of 1:50 000 of the Litoměřice district

Legend for Figure 13



– To elaborate a methodology of grouping parent materials from the currently valid classification system (till now they have been substituted by parent materials from the soil forms map).
– To resolve the geomorphological issues.

An objective exceeding the extent of working with the data from a pilot area is to elaborate a methodology which would enable us to: make use of the archive soil data as a basis for new surveys and researches; increase efficiency of the work on digital databases, including their faster updating; incorporate the requirement to meet the basic statistical prerequisites for the data stored in these databases; apply pedotransfer rules when updating the databases; intervene professionally in the soil pricing process; revive the teaching of land valuation and related subjects; specify the currently valid soil classification system.

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