Study of Anthropogenic Soils on a Reclaimed Dumpsite and their Variability by Geostatistical Methods

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Abstract: Soils of reclaimed dumpsites after coal mining are considered as typical anthropogenic soils. These soils are at the beginning of their development and have certain specific characteristics. The aim of this study was to describe a soil survey performed on anthropogenic soils of a reclaimed dumpsite, to analyse spatial variability of selected properties using geostatistical methods, and to evaluate the development of reclaimed dumpsite soils. It has been shown that geostatistical methods are suitable for a description of anthropogenic soil properties and their variability. However, characterization of soil properties on the border between areas with different types of reclamation can be difficult due to sharp discontinual transitions caused by human activity. Properties of these soils vary profoundly greatly dependent on the properties of the soil substrate and the type of reclamation. The average content of organic carbon in the topsoil (0–20 cm) was 1.92% on the area covered with a layer of natural topsoil and 0.92% on the area covered by a layer of loess. An initial A horizon can develop even in 10 years under favourable conditions.

Keywords: soil survey; soil reclamation; anthropogenic soils; spatial variability; geostatistics

Soils of reclaimed dumpsites after open-cast coal mining represent a specific group of soils. Anthropogenic activities are the main soil-forming factor.

The morphology of reclaimed dumpsite soils differs from the morphology of natural soils. These soils are very young and are developed from stripped overburden materials which can be very heterogeneous. However, the initial stratification of deposited materials represent just anthropogenic substrates. The specific conditions for soil development can be achieved only after their reclamation (Němeček *et al.* 2001). Therefore, the properties of soils developed at reclaimed dumpsites are often determined by human-controlled influences rather than natural processes. It means that man determines the type and method of reclamation, materials used for reclamation, relief of dumpsites, etc. Natural soils in close vicinity to mines and dumps have been developing by pedogenic processes for thousands of years and therefore have achieved a certain form of equilibrium with their environment (Sencindiver & Ammons 2000). Even if soils of reclaimed dumpsites can become very similar to natural soils after a period of time, some of their properties, even the unfavourable ones, can remain unchanged. The properties of these soils (particle size distribution, pH, sorption capacity, etc.) can greatly vary in dependence on the properties of the soil substrate from which they are formed.

Natural soil formation is influenced by many pedogenetic factors – substrate, climate, organisms, human activity, water, relief and time. The

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development time of reclaimed dumpsite soils is too short for the factors to manifest fully their effect. According to Sencindiver and Ammons (2000) freezing and thawing, swelling and shrinking processes, decomposition and resynthesis of organic matter, aggregation of soil particles, etc., are the main soil forming processes influencing the development of reclaimed dumpsites soils. The soil structure and its stability were also well studied in soils developed on reclaimed dumpsites (Valla *et al.* 2000a). The humic horizon (A) of reclaimed dumpsite soils can develop in a relatively short time, Sencindiver and Ammons (2000) refer to 5 years. This initial A horizon is thin but its properties differ from the soil substrate (looseness due to root growing, accumulation of organic matter, darker colour, development of soil structure, etc.). An artificially created humic horizon is well recognizable in reclaimed soils covered by a layer of natural topsoil. This anthropic humic horizon usually keeps the properties of the original horizons; however it can degrade. Some inner horizons such as the cambic horizon (Bw) or the weakly developed luvic horizon (Bt) can also be found in reclaimed dumpsite soils of different age. Moreover, some specific horizons such as sulphuric (soils developed from very acidic substrates with oxidation of pyrite), or spodic (developed on very poor sandy materials) can be formed (Sencindiver & Ammons 2000). Kozák *et al.* (2001) were also studying development of soils on reclaimed dumpsites.

For planning the future exploitation of these soils, for their conservation and the protection of other associated natural resources, it is very important to obtain and process detailed information about these soils. Therefore, good preparation and implementation of soil survey is necessary. Methods that can work with limited soil data using other supplemental information are used more frequently in soil survey recently (McBratney *et al.* 2000). These methods can also alternatively interpret data that can then be used in other applications. Geostatistical methods provide suitable tools for spatial description of soil properties (Borůvka 2001). Their use can be specific in various conditions. Soils developed on reclaimed dumpsites are an example. Spatial variability of these anthropogenic soils is different from the spatial variability of natural soils, which causes a difficult characterization of their properties (Borůvka & Kozák 2001).

The aim of this study was to describe a soil survey performed on anthropogenic soils of a reclaimed dumpsite, to analyse spatial variability of selected properties using geostatistical methods, to evaluate the development of reclaimed dumpsite soils and to predict future development of soils under study.

MATERIAL AND METHODS

A soil survey of anthropogenic soils developed after open-cast coal mining was performed on the Pokrok dumpsite, which is an outer dumpsite of the Bílina mine belonging to the Northbohemian Mining Company. The dumpsite is located near to the small town of Duchcov. The dumpsite was divided into several areas according to the type and age of reclamation (Figure 1). One of them is Pokrok I., where method used for reclamation was no covering of dumpsite surface. Then there are areas Pokrok II.A and Pokrok III.A, which were reclaimed by covering the dumpsite deposited material with approximately 50 cm of natural topsoil. Area Pokrok II.B was covered with a layer of loess. The rest of the dumpsite was left under technical reclamation. The age of the studied areas is by 10 to 30 years starting from the biological reclamation process. Areas Pokrok II.A, Pokrok III.A and Pokrok II.B (total area of 91 ha) were all included in the soil survey. Unaligned systematic sampling was used for collecting samples, all sampling sites were located using GPS (Figure 1). All 128 samples were collected from the upper 20 cm. In addition, three dug pits (on Pokrok II.B, Pokrok III.A and Pokrok I) were used for the profile description leading to a better assessment of anthropogenic soils development on reclaimed dumpsites. Samples in these pits were taken from all layers (horizons, respectively).

Selected basic soil characteristics were determined by commonly used methods. Exchangeable soil pH (pH_{KCl}) was measured potentiometrically in 0.2M KCl extract (1:2.5; w:v) (Zbíral 2002). The humus quality was assessed by the ratio of absorbances of sodium pyrophosphate soil extract (1:20; w:v) at the wavelengths of 400 and 600 nm (A_{400}/A_{600}, Pospíšil 1981). Organic carbon content (C_{org}) was determined oxidimetrically by a modified Tjurin method (Pospíšil 1964). Particle size distribution was determined by the areometric method (Valla *et al.* 2000b), however only some data are presented here.

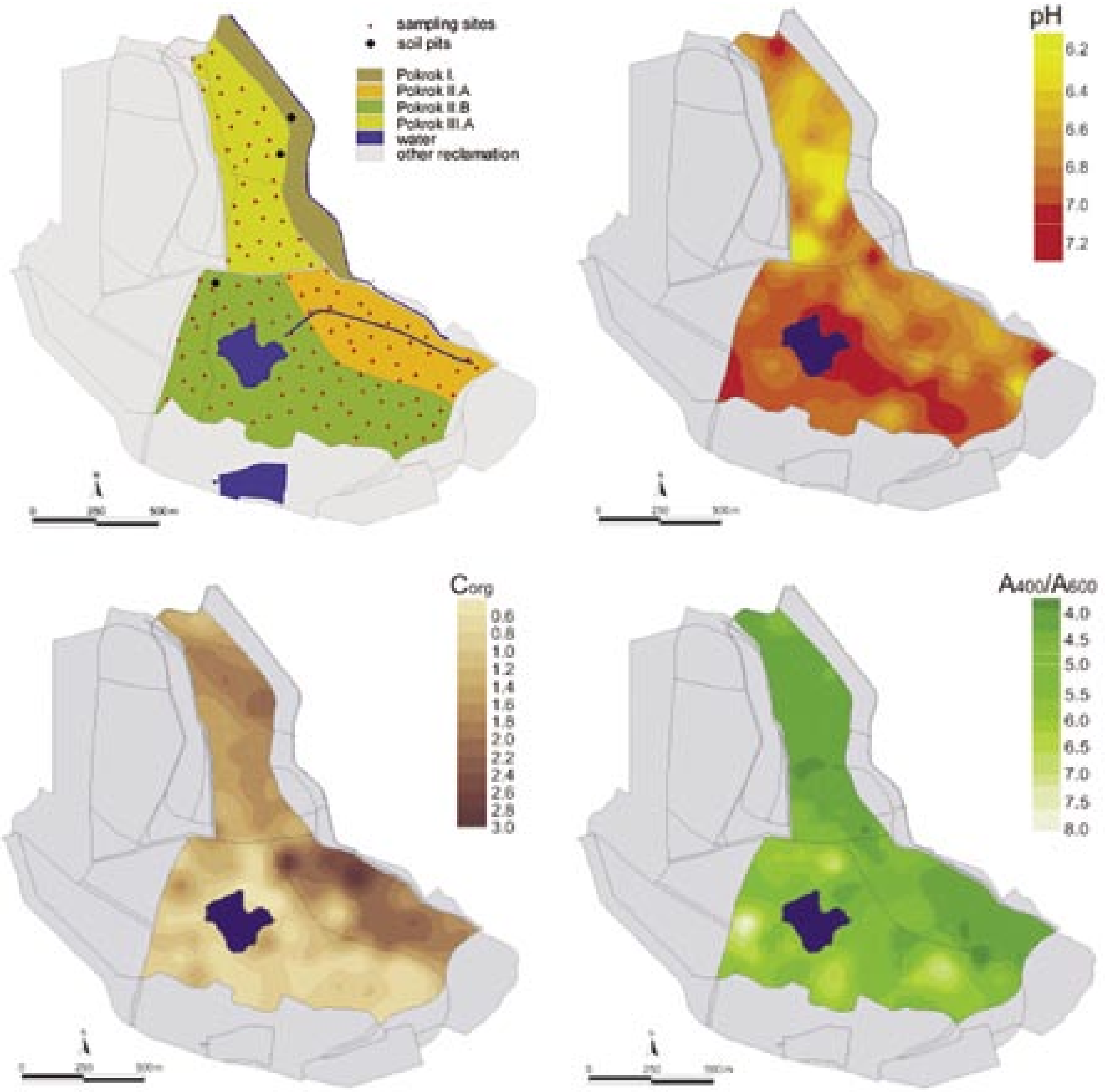


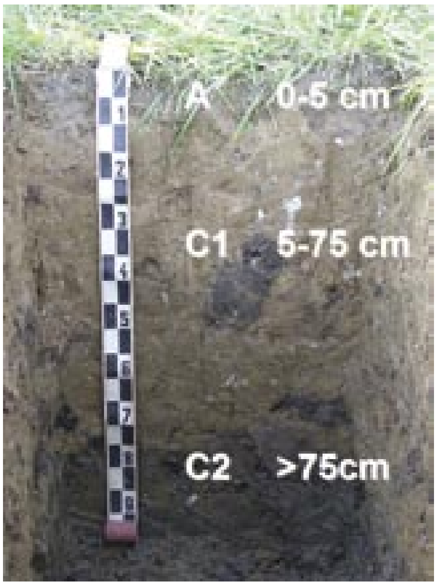
Figure 1. Sampling design and cartograms of determined soil properties

Data were statistically processed using Statgraphics plus 4.0 statistical software (Manugistics 1997). Spatial variability was described using GS+ geostatistical software (Robertson 2000). The dependence of the semivariance of soil characteristics on the distance was expressed by means of variograms. Spatial interpolation was done by means of block kriging that suitably describes spatial variation and trends of larger extent and eliminates local extremes.

RESULTS AND DISCUSSION

The results of all statistical analyses are shown in Table 1. Soil properties of Pokrok II.A and Pokrok III.A look very similar, but significant differences were found in C_{org} (Table 2). It could be possibly caused by a higher accumulation of organic matter on the area Pokrok II.A, where the grass cover is in better condition. The soil properties of the area Pokrok II.B are different due to a different technique of reclamation (Table 2).

Variograms of the studied soil properties were calculated for the whole area and for individual areas separately. Variograms of soil properties of the whole area were described by exponential models and show a small proportion of nugget variance (Table 3). Spatial variability is thus assessed as strong. A small proportion of nugget is also observed in most variograms describing

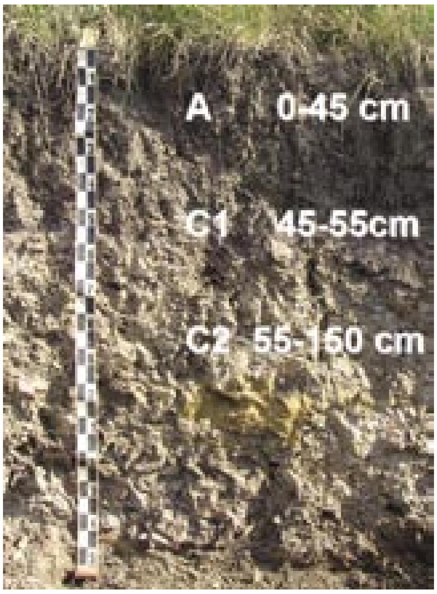


colour 7.5 YR 3/4, crumb, clayey loam, moist, friable, direct transition to

colour 7.5 YR 5/6, angular blocky, loam, moist, friable, $CaCO_3$ concretions , dark mottles of organo-mineral material, direct transition to

colour 7.5 YR 4/3, structureless, clay, moist, compacted

Figure 2. Soil profile description at the area Pokrok II.B



color 7.5 YR 2/2, polyedric and/or moderately prismatic, loamy, dry, coherent, sporadically occurrence of loess

and rounded stones, sporadically calcareous, distinct transition to C1 (with presence of high amount of coal)

angular blocky or platy disintegration of clays, clayey, dry, coherent, presence of coal, rounded stones, burnt clays, non-calcareous

Figure 3. Soil profile description at the area Pokrok III.A

partly decomposed leaf litter

color 7.5 YR 3/2, crumb, clayey loam, moderately moist, friable, non-calcareous, distinct and around pores transition to

color 7.5 YR 5/3 and 7.5 YR 4/2, structureless, clay, moderately moist, presence of coal, rounded stones

Figure 4. Soil profile description at the area Pokrok I

Table 1. Summary statistics of soil properties for separate studied areas

Summary statistics	Pokrok II.A			Pokrok III.A			Pokrok II.B		
	pH_{KCl}	C_{org}(%)	A_{400}/A_{600}	pH_{KCl}	C_{org}(%)	A_{400}/A_{600}	pH_{KCl}	C_{org}(%)	A_{400}/A_{600}
Count	31	31	31	35	35	35	62	62	62
Average	6.84	1.92	4.61	6.71	1.62	4.41	7.04	0.92	5.68
Variance	0.06	0.53	0.37	0.11	0.12	0.09	0.03	0.28	1.28
St.dev.	0.24	0.73	0.61	0.34	0.34	0.30	0.16	0.53	1.13
Minimum	6.19	0.32	3.97	6.01	0.72	4.02	6.47	0.00	3.12
Maximum	7.32	3.65	6.52	7.45	2.43	5.26	7.41	2.66	8.97
CV (%)	3.5	38.2	13.1	5.0	21.3	6.9	2.3	57.8	19.9
Range	1.13	3.33	2.55	1.44	1.71	1.24	0.94	2.66	5.85

CV(%) – coefficient of variation

individual reclaimed areas, except variograms of C_{org} at Pokrok II.A and Pokrok II.B and variogram of A_{400}/A_{600} at Pokrok III.A.

The area Pokrok II.B is distinguished from the other two areas due to a different type of reclamation (Figure 1). On C_{org} cartogram, there is a change indicating a sharp transition between the areas with different reclamation. Geostatistical methods were found suitable mainly for the description of soil properties which are changing continually. It is possible to describe this sharp transition caused anthropogenicly by creating cartograms for each area separately and combining these cartograms into the final map. The disadvantage lies in the use of variograms with greater nugget variances calculated from smaller numbers of input data.

Table 2. Multiple range test for the determination of differences between the areas (LSD 95%)

Area	C_{org}	A_{400}/A_{600}	pH_{KCl}
Pokrok II.A	1.92 c	4.61 a	6.84 ab
Pokrok II.B	0.92 a	5.67 b	7.04 b
Pokrok III.A	1.62 b	4.41 a	6.71 a

Different letters in each column indicate statistically different values at $P < 0.05$

Three soil pits were studied for the assessment of anthropogenic soils development. On Pokrok II.B the artificial layer of loess due to the reclamation method used is clearly visible on the soil profile (Figure 2). However, a 5 cm thick initial A horizon with well developed structure has developed in the upper part of this artificial layer. This horizon has different properties to the underlying horizons (Table 4). Rather compacted waste rocks are under the layer of loess (70 cm due to the location of the soil pit on a moderate slope). Soil substrate has a slightly alkaline pH only in this case. This is due to the fact that no coal and pyrite oxidation occurred in this layer. The whole soil profile down to 75 cm is biologically active (earthworms, roots, etc.). This soil definitely holds artificial features such as artificial layering and sharp transitions between particulate horizons. Dark mottles in the C1 horizon resembling crotovinas are the admix-

Table 3. Parameters of calculated variograms

	C_{org}				A_{400}/A_{600}				pH_{KCl}			
	mod.*	nugget	sill	range	mod.*	nugget	sill	range	mod.*	nugget	sill	range
Whole area	E	0.001	0.550	133	E	0.001	1.712	65	E	0.000	0.075	103
Pokrok II.A	L	0.360	0.378	566	S	0.001	0.936	118	E	0.018	0.056	120
Pokrok II.B	P	0.175	0.175	-	E	1.938	3.877	2110	E	0.001	0.875	85
Pokrok III.A	S	0.062	0.129	487	P	0.087	0.087	-	E	0.000	0.127	113

* mod. – variogram models: E – exponential model, L – linear model, S – spherical model, P – pure nugget

Table 4. Soil profile characteristics at Pokrok II.B, Pokrok III.A and Pokrok I

Horizon	Depth (cm)	pH_{H_2O}	pH_{KCl}	C_{org} (%)	A_{400}/A_{600}	Clay (%)	Silt (%)	Sand (%)
Pokrok II.B								
A	0–5	7.21	7.41	2.04	5.94	25.2	40.7	34.1
C1	5–75	7.39	7.38	0.58	4.95	26.0	39.4	34.6
C2	> 75	7.18	7.38	0.53	7.37	67.7	19.2	13.1
Pokrok III.A								
A	0–45	7.08	7.35	1.67	4.49	22.3	45.7	32.0
C1	45–55	3.92	4.12	5.66	3,60	nd.	nd.	nd.
C2	55–150	4.09	4.15	2.23	6.28	67.7	25.3	7.0
Pokrok I								
O	1–0	nd.	nd.	nd.	nd.	nd.	nd.	nd.
A	0–1	6.22	6.29	5.91	5.44	61.8	29.9	8.3
C	1–60	4.71	4.96	1.93	5.82	65.5	25.5	9.0

nd. – not determined

ture of topsoil of the original soil from which the loess was used for reclamation.

On Pokrok III.A the dumpsite surface was covered with a layer of topsoil 50 cm thick. This anthropogenic A horizon is clearly apparent in the soil profile (Figure 3). A layer about 10 cm thick with a very high content of coal is underlying the A horizon. The soil substrate holds many artificial features – polyedric or platy disintegration of clays that is not parallel to the soil surface, presence of stones and boulders, and presence of coal. The last two layers or horizons mentioned have very low pH (Table 4) because of the high content of coal and the occurrence of pyrite oxidation. Biological activity is only evident in the anthropogenic A horizon.

Pokrok I was reclaimed without covering the dumpsite surface; poplar trees were planted directly into the dumped earth about 30 years ago. The whole soil profile is very poorly developed (Figure 4). The initial A horizon (1 cm thin) has better soil properties then the underlying C horizon (Table 4). This horizon also interferes around pores and cracks into the C horizon. The C horizon is composed from overburden clays, therefore it has a heavy texture and is compacted. The platy disintegration of clays is variously orientated; usually the orientation of disintegration is not parallel to the surface. Roots of scrub penetrate down to this horizon, but only along the cracks in clays, not through the layers of clays. This horizon holds also artificial features such as presence of stones and boulders and admixture of coal. The decrease of pH of thin horizon was ascribed to the pyrite oxidation (Table 4). These unfavourable soil properties have caused the rather poor state of the poplar trees, grown on the locality.

This paper shows that the use of geostatistical methods is suitable for soil properties description not only of natural soils, but also of anthropogenic soils. The characterization of soil properties on the border between areas with different types of reclamation can be however difficult due to sharp discontinual transitions caused by human activity. To create separate cartograms for each reclaimed area could be an appropriate solution. The development of reclaimed dumpsite soils is a complicated process dependent mainly on the type of reclamation, soil substrate properties and the type of soil cover. The duration of pedogenetic process being in progress is also an important factor. However, it was proved that an A horizon can develop even in 10 years under favourable conditions.

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