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Chapter V

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Soil Transformations in an Urban Landscape

INTRODUCTION

Urbanized areas generate specific transformations of environmental conditions that can exceed the capabilities to maintain homeostasis of soil systems. Soil Thematic Strategy (COM, 231), adopted by The European Parliament and the European Council in 2006, mentions the loss of land resources for urbanization as one of main risks to landscape functioning.

The area adjacent to St. Jacob's Basilica in Szczecin, located in the city centre, has been under strong human impact for about 1000 years, including the period of 600 years in the past, when it was subject to intensive, "concentrated" human activity, due to its isolation inside the city's walls and fortifications [TUREK-KWIATKOWSKA, BIAŁECKI 1991].

The documented origins of settlement in the area immediately adjoining the Basilica date back to the turn of the 10th century [KOTLA 2001]. The town and its settlements clustered around St. Jacob's Church (built in 1187) were surrounded by stone-brick walls in the 13th century. At the beginning of the 14th century, Szczecin (the area of 54 ha called at present "the Old Town") was fully walled and moated. A ring of huge fortifications built in the 17th century outside the medieval wall and moat, without disturbing their structure, surrounded the town and, as a consequence, inhibited its growth. The needs of expanding population in the city were addressed by dense housing and replacing medieval tenements with new, higher buildings. At the beginning of the 19th century, Szczecin was still enclosed by tight fortification walls. Their demolition in 1873 stimulated its rapid spatial development [BARANOWSKA 2001].

While a negative influence of urbanization on physical and chemical properties of the soil is well recognized, soil enzymatic activity in municipal areas has not been extensively investigated. Biochemical methods based on enzymatic tests allow to obtain synthetic indicators of evolution of urban soils [BIELIŃSKA 2007]. Optimization of management and protection of urban ecosystems will be possible after identification of processes involved in energy flow and matter cycle as well as their control mechanisms.

The aim of the study was to present a comprehensive evaluation of the soil system, with the emphasis on specific biochemical soil processes and their significance for the 1000-year urban soil located in the area of the Old Town in Szczecin.

MATERIAL AND METHODS

The study was conducted on 11 soil samples taken from 3 boreholes drilled by St. Jacob's Basilica in the area of the Old Town in Szczecin (Fig. 1).

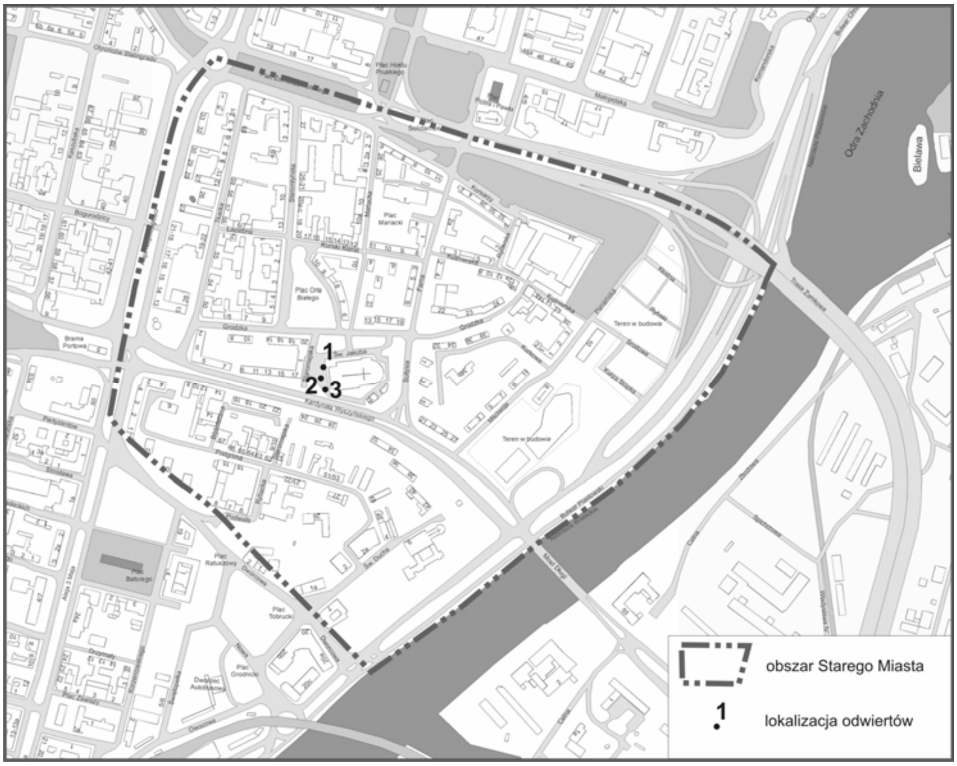

Fig. 1. Location of the boreholes

Boreholes (BH), commissioned by the Department of Erosion and Soil Reclamation of West Pomeranian University of Technology in Szczecin, were made in January 2007 by Przedsiębiorstwo Geologiczne "Geoprojekt" Szczecin. The exploratory drilling was conducted with a rotary-percussive probing auger slowly bored into the ground. Soil samples were collected from the drill at the depths: 0-50, 50-120, and 120-170 cm (BH1); 20-80, 80-130, and 170-210 cm (BH2); 20-70, 70-120, 120-190, and 190-230 cm (BH3). In the case of BH2 and BH3, samples were not collected from the depth of 0-20 cm because that layer consisted of cobbles and pavement, without soil material. A general characteristics of the material studied is presented in Table 1.

The soil samples were dried in a laboratory at room temperature and sifted through a sieve with the mesh size of 1 mm. The following analyses were carried out: texture was determined using Casagrande's areometric method modified by Prószyńki; pH in 1 $mol \cdot dm^{-3}$ KCl (ISO 10390); $CaCO_3$ in Scheibler apparatus; organic mater content by loss-on-ignition at the temperature of 550°C; total contents of Zn, Pb, Cd, Ni, Cr, and Cu by AAS after mineralization of the sample in the mixture of concentrated HNO_3 and $HClO_4$ (ratio 1:1); activities of enzymes were also analyzed – dehydrogenases [THALMANN 1968], acid phosphatase and alkaline phosphatase [TABATABAI, BREMNER 1969], urease [ZANTUA, BREMNER 1975], and protease [LADD, BUTLER 1972]. All the analyses were done in 3 replications.

Data analysis was performed using Statistica 6.0 PL software.

RESULTS AND DISCUSSION

The data in Table 1 show that the thickness of anthropogenic layer attains about 2.0 m in the studied soil. SZPONAR [2003] reports that the thickness of cultural layer in soils of Polish cities varies from 1.5 to 6.0 m, reaching up to 8.0 m on occasion. Building rubble was the main anthropogenic material in the investigated soils. Layers with a large share of construction debris lied at the depth from 20 to 170 cm, depending on the borehole (Tab. 1).

The long-term study by GREINERT [2003] indicates that construction materials, such as chips of concrete, rubble, mortar, bricks and tiles, are the most abundant human artefacts in urban soils. The greatest share of skeletic phase was found in the debris layers (Tab. 1). The occurrence of skeletic phase (> 1 mm in diameter) in urban soils is one of the indicators of duration and intensity of human impact in the area [GREINERT 2003].

The soil material collected from three neighbouring boreholes (Fig. 1), was diverse in respect of texture (including sand, loamy sand, sandy loam, and silt), depending on the borehole and sampling depth (Tab. 2). Diversity in texture is typical of urban areas and results from introduction of great amounts of construction rubble, sand and other materials (used for flooring, levelling, filling) into a soil environment [GREINERT 2003].

Properties of the investigated soil material Table 1

Borehole No.	Depta	Skeletic phase	Fine earth	Description of soil material (type and quantity of anthropogenic input)
	[cm]	[%]		
1	0-50	12.1	87.9	Mortar, bricks, glass, bones – more than 90% of the sample (v/v)
	50-120	26.0	74.0	Construction debris with a higher share of mortar than bricks – more than 80% of the sample (v/v)
	120-170	9.1	90.9	Mortar, bricks – c.a. 40% of the sample (v/v), and gravel and stones
2	20-80	8.7	91.3	Mainly mortar and bricks – more than 90% of the sample (v/v)
	80-130	11.8	88.2	Construction debris and bones – more than 80% of the sample (v/v)
	130-170	8.9	91.1	Construction debris and bones – more than 80% of the sample (v/v)
	170-210	5.9	94.1	Bones, brick fragments – c.a. 40% of the sample (v/v), and natural gravel
3	20-70	36.0	64.0	Debris and floor stones – more than 80% of the sample (v/v) and bones
	70-120	22.2	77.8	Construction debris – more than 80% of the sample (v/v), and bone chips
	120-190	32.5	67.5	Domination of cinder and bones, small amounts of bricks and mortar – more than 80-90% of the sample (v/v)
	190-230	5.9	94.1	Natural coarse gravel only

Most of the investigated soils were characterized by high values of pH in 1 mol·dm^{-3} KCl, namely 8.2-9.9. Only the sample from BH1, within the depth of 0-50 cm, had clearly lower pH$_{KCl}$ – 7.6 (Tab. 2). Such high pH values resulted from the presence of large quantities of $CaCO_3$ in the soils (Tab. 2). Anthropogenic calcium carbonate was introduced into the soil environment with construction debris containing fragments of sandy-lime mortar. It is noteworthy that construction debris enriches soils with so called secondary carbonates, consequently raising their salinity. CZARNOWSKA [1995] emphasizes that alkalisation of urban soils is connected with deposition of alkaline dust and salinity.

Selected properties of the studied soils Table 2

Borehole No.	Depta	Fraction [%]			Organic matter	$CaCO_3$	pH_{KCl}
	[cm]	Sand	Silt	Clay	[%]		
1	0-50	54.9	27.1	18.0	7.3	2.1	7.6
	50-120	59.9	19.1	21.0	2.9	10.2	8.7
	120-170	48.2	23.8	28.0	2.7	1.4	8.2
2	20-80	70.0	21.0	9.0	1.6	6.0	9.9
	80-130	58.4	24.6	17.0	1.6	4.7	8.7
	130-170	54.8	23.2	22.0	1.9	4.5	8.4
	170-210	46.8	28.2	25.0	1.4	7.0	8.4
3	20-70	65.9	17.1	17.0	1.9	5.6	8.6
	70-120	56.9	22.1	21.0	2.3	6.1	8.3
	120-190	56.9	20.1	23.0	2.0	4.8	8.2
	190-230	33.5	40.5	26.0	1.2	6.9	8.4

The profile distribution of organic matter within the whole soil thickness was quite regular, only in the material from BH1 its content in the surface layer (0-50 cm) was about 2.5 times higher than in the deeper layers (50-120 and 120-170 cm), (Tab. 2). Organic matter concentrations within the deepest soil layers from BH2 and BH3 were clearly lower (Tab. 2), which was the effect of the predominance of natural mineral material (Tab. 1). A high content of organic matter observed at a greater depth (more than 2 m) is characteristic for centuries-old urban soils and is connected with accumulation of household waste on the soil surface and its spatial displacement during earth and construction works [Zimny 2005].

The analyzed soils were characterized by a great diversity of heavy metal concentrations in the individual boreholes and soil layers (Tab. 3). It may be connected with soil material segregation in the course of urban transformations of the area and with deposition of anthropogenic pollutants all over the place.

The highest Zn, Pb, Cd, and Cu concentrations were noticed in the surface layer (0-50 cm) of the soil from BH1 (Tab. 3). An elevated content of trace elements in the surface layer is a hallmark of urban soils [Dąbkowska-Naskręt, Kobierski 1998; Jakubus, Czekała 1998]. According to the scale proposed by IUNG [Kabata-Pendias et al. 1993], the studied urban soils exhibit the enrichment with zinc and lead (in the surface layers solely) as well as with cadmium and copper (Tab. 4). Weak pollution of the soil from BH1 (2nd degree) was observed in the case of Zn and Pb. The soil samples from BH2 and BH3 had elevated contents of Pb (1st degree). A very high concentration of Cu (4th degree) in the surface layer of the soil from BH1 is noteworthy. Increased contents of copper (1st degree) occurred to the depth of 130 cm (BH2) and 190 cm (BH3).

Total content of heavy metals in the soils studied Table 3

Borehole No.	Depth [cm]	Zn	Pb	Ni	Cd	Cu	Cr
		[mg·kg^{-1} of soil]					
1	0-50	265.3	103.5	12.9	2.87	225.3	20.9
	50-120	34.2	59.9	10.9	1.68	34.6	13.8
	120-170	50.5	39.3	15.1	1.41	31.7	21.8
2	20-80	21.4	75.8	9.7	2.21	45.5	14.0
	80-130	28.5	34.4	11.1	1.60	34.8	17.0
	130-170	31.0	48.1	15.1	1.74	19.8	18.9
	170-210	33.8	38.8	14.0	1.42	17.6	20.6
3	20-70	41.4	89.4	17.2	2.45	33.9	20.2
	70-120	38.7	54.0	15.5	1.76	35.0	18.6
	120-190	44.6	46.7	16.3	1.72	34.6	17.2
	190-230	27.7	32.2	12.4	1.76	11.6	17.7

Cadmium values found in the whole thickness of the studied soils exceeded its natural levels (Tab. 4). The highest amounts of Cd (2nd degree) were stated in the surface layers. In the case of BH2 and BH3, contamination with cadmium within the deep soil layers could also be caused by its mobility together with the parent material. Heavy metal contamination of soil under conditions of centuries-old urbanization is related to urban soil management and introduction of natural and technogenic substrates varying in amount, origin, composition, ways of insertion and spatial translocation [GREINERT 2003; ZIMNY 2005]. As KOLLENDER-SZYCH et al. [2008] point out, urban soil management becomes a soil-forming factor.

Amounts of nickel and chromium in the studied soils were within the range of their natural contents (Tab. 4).

Degrees of soil pollution according to KABATA-PENDIAS et al. (1993) Table 4

Borehole No.	Depta [cm]	Zn	Pb	Ni	Cd	Cu	Cr
1	0-50	II	II	0	II	IV	0
	50-120	0	0	0	I	I	0
	120-170	0	0	0	I	I	0
2	20-80	0	I	0	II	I	0
	80-130	0	0	0	I	I	0
	130-170	0	0	0	I	0	0
	170-210	0	0	0	I	0	0
3	20-70	0	I	0	II	I	0
	70-120	0	0	0	I	I	0
	120-190	0	0	0	I	I	0
	190-230	0	0	0	I	0	0

0, I, II, IV – degrees of soil pollution

The soil enzyme activities varied, depending on the borehole, depth, and type of enzyme (Tab. 5).

Table 5

Soil enzymatic activit

Borehole No.	Depth [cm]	ADh	APac	APal	AU	AP
1	0-50	9.12	89.86	148.73	13.54	29.34
	50-120	2.28	13.41	14.67	1.38	17.14
	120-170	3.45	34.68	33.14	0.49	10.98
2	20-80	3.08	7.12	4.98	1.47	11.59
	80-130	2.11	13.54	15.11	0.69	10.46
	130-170	1.98	11.48	17.21	0.52	10.11
	170-210	1.74	10.63	14.05	0.32	11.87
3	20-70	2.61	10.97	10.42	0.96	13.39
	70-120	2.89	18.16	18.93	0.48	12.27
	120-190	2.03	30.35	26.74	0.32	11.30
	190-230	1.76	16.73	17.87	0.25	9.74

ADh – dehydrogenases ($cm^3\ H_2 \cdot kg^{-1} \cdot d^{-1}$); APac – acid phosphatase and APal – alkaline phosphatase ($mmol\ PNP \cdot kg^{-1} \cdot h^{-1}$); AU – urease ($mg\ N\text{-}NH_4^+ \cdot kg^{-1} \cdot h^{-1}$); AP – protease ($mg\ tyrosine \cdot g^{-1} \cdot h^{-1}$)

In the surface layer (0-50 cm) of the soil from BH1, where the highest concentrations of Zn, Pb, Cd, and Cu were found (Tab. 3), many-fold higher activities of all the enzymes studied were stated as compared to the other soil samples. The stimulation of enzymatic activity was connected with the high concentration of soil humus – 7.3% and with the soil reaction, pH_{KCl} 7.6 (Tab. 2), favourable for the metabolic activity of microorganisms. The presence of carbon substrates induces and stimulates enzyme biosynthesis by soil microorganisms [Fierer et al. 2003]. It should be emphasized that organic matter not only activates metabolic processes of microorganisms, but also influences positively the rate of pollutant degradation [Kanchikerimath, Singh 2001]. A high concentration of $CaCO_3$ in the construction waste of urban soils impacts their deacidification and improves the sorption complex [Zimny 2005], making heavy metals less available to soil microorganisms [Kucharzewski, Nowak 2004]. Łabuda and Niemira [2000] stress that with an increase of organic matter in soil, a high rise in the capacity of soil sorption complex is observed. Sorption and desorption of heavy metals depend mainly on the amount of organic matter in soil. Those elements are built into permanent soil organic complexes. The present study found no significant correlation between activities of the analyzed enzymes and determined concentrations of heavy metals in the soils.

Alleviation of the negative effects of heavy metals on enzyme activities in the surface layer of the soil from BH1 could also result from its weak alkaline reaction (Tab. 2). Soil reaction is considered the main factor determining availability of heavy metals in soil [BADORA 1999]. Exchangeable fractions of metals that are easily assimilable by soil microorganisms predominate in soils with pH < 4.5, and their amounts decrease with increasing soil pH [CHŁOPECKA 1996]. BADURA and PIOTROWSKA-SEGET [2000] point out that bacteria have developed numerous defence mechanisms which allow them to survive in soils strongly contaminated with metals. Tolerance and adaptation of microorganisms to metals have been extensively described in the literature [HUYSMAN et al. 1994; BADURA 1997; NOWAK et al. 2004]. A lower sensitivity of microorganisms to high metal concentrations may result from their adaptability to unfavourable conditions, and also from the ability of soil sorption systems to reduce toxic effects of metal ions [BADURA 1997]. ACCORDING TO NOWAK et al. [2004], an increase in enzymatic activity of microorganisms frequently observed with an increase in heavy metal contents in soil may be caused by disturbances of metabolic transformations in the cell. It should be emphasized that the soil enzymatic activity in the layer of 0-50 cm from BH1 was clearly higher than in the soils with undisturbed biological processes [BIELIŃSKA, MOCEK-PŁÓCINIAK 2009].

Heavy metals, as agents activating the synthesis of numerous enzymes (such as dehydrogenase, alkaline phosphatase, or urease), stimulate some biochemical processes in the soil environment, while substances that strongly bind the metals act as inhibitors of enzymes [EHRLICH 1997]. More than 25% of all enzymes include a tightly bound metal ion which is essential for their activity. Metal ions are also components of enzyme activators [NIKLIŃSKA, CHMIEL 1997]. However, the decrease of enzymatic activity influenced by heavy metals is more frequently reported in the literature [FRANKENBERGER, TABATABAI 1991; DOLMAN, HAANSTRA 1989; FU, TABATABAI 1989; MARZADORI et al. 1996; ROANE 1999; NOWAK et al. 1999; ŠMEJKALOVA et al. 2003; WYSZKOWSKA, KUCHARSKI 2003]. Studies on the effect of heavy metal contamination on biological properties of soils have been generally based on pot experiments under conditions different from those found in natural ecosystems. The study of NOWAK et al. [1999] showed that Cu and Pb concentrations 100 times higher than their limits proposed by KABATA-PENDIAS et al. [1993], caused permanent inhibition of the activity of dehydrogenases, acid phosphatase, alkaline phosphatase, and urease, whereas in the case of a 10-fold higher dose of those metals, the stimulation of the activity of dehydrogenases and urease for Cu was stated. MARZADORI et al. [1996] observed (in a model study) a negative effect of lead pollution on soil enzymatic activities only at the highest concentration of Pb. In simulation experiments with the use of metal doses that may occur sporadically, for example due to industrial accidents, the effects can be easily measured in a short period of time [Bielińska 2006]. However, such models do not reflect complex relations between the activity of soil microbes and soil components 'buffering' an impact of external factors. The study by Belińska 2006] confirmed the occurrence of a defence mechanism which, in natural soils, protects enzymes from environmental stresses.

Activities of dehydrogenases, phosphatases, and protease within the whole thickness of the studied urban soils, except for the soil layer of 0-50 cm from BH1 (Tab. 5), were typical of those found in humus soil horizons in natural ecosystems, for example in arable soils [Bielińska 2001]. A decrease of enzymatic activity with soil depth observed in natural ecosystems is mainly related to humus distribution within profiles and decreasing amounts of carbon substrates available to microorganisms and enzymes. On the other hand, the urease activity was low in most of the samples (Tab. 5), which could result from limited availability of urea. Urease jest synthesized only in its presence [Stępniewska, Samborska 2002]. In the opinion of Carbrera et al. [1994], uerase perfectly adapts itself in each soil environment, regardless of temperature, moisture, or reaction.

In summary, the activities of dehydrogenases, both acid and alkaline phosphatases, and protease reflected anthropogenic transformations of the studied urban soils, which is indicated by highly significant linear correlation coefficients between the activities and the organic matter content in the studied soil (Tab. 6).

Table 6

Correlation coefficients between activity of enzymes and organic matter content

	Dehydrogenases	Phosphatases		Urease	Protease
		Acid	Alkaline		
Organic matter	0.86*	0.84*	0.82*	n.s.	0.75*

Explanations: *significant at $p = 0.05$; n.s. – not significant

Diverse effects of soil conditions on the activity of biochemical parameters is confirmed by the values of coefficients of determination (R^2) of multiple regression equations. Those values indicate that from 58 to 72% of variability of activities may be described by the analyzed soil properties – the activity of dehydrogenases (R^2=72%), acid phosphatase (R^2=68%), alkaline phosphatase (R^2=63%), and protease (R^2=58%). In the case of urease activity (R^2=43%), the variability was largely dependent on other factors, not included in this study.

CONCLUSIONS

1. The presence of large quantities of anthropogenic material in the urban soils studied (c.a. 80-90% of the sample (v/v)), mainly construction rubble, resulted in strong alkalization of the soil environment. This indicates a long-term and intensive human impact on the soils located in the area adjacent to the St. Jacob's Basilica in Szczecin.
2. The content of organic matter in the studied soils was high and its profile distribution relatively regular; the exception was the material from BH1 where humus content within the surface layer (0-50 cm) was about 2.5 times higher than in the deeper layers.
3. The highest concentrations of Zn, Pb, Cd, and Cu were stated in the surface layers of the urban soils investigated, which proves the weak mobility of heavy metals resulting from high pH values and a high content of organic matter.
4. The activity of soil enzymes fluctuated over a wide range but clearly depended on the intensity of anthropogenic impact, which was confirmed by significant values of linear correlation with organic matter content in the soils.
5. Enzymatic activity in the layer of 0-50 cm within the soil from BH1 was clearly higher than in the soils with non-disrupted biological processes.
6. Activities of dehydrogenases, acid phosphatase, alkaline phosphatase and protease in the whole thickness of the majority of analyzed urban soils were typical of those present in the humus layer in natural land ecosystems.
7. Urease activity was very low in most of the soil samples studied. A diverse effect of soil conditions on the activity of individual biochemical parameters is confirmed by the values of coefficients of determination (R^2) of multiple regression equations.
8. The results obtained show that measurements of the activities of soil enzymes reflect transformations in urban soil.

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