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Spatial and temporal environmental changes of urban forested park – The Royal Łazienki Park in Warsaw example

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Abstract: The goal of this paper is to recognize spatial and temporal dynamics of environmental changes under human impact in the park's. Detailed environmental studies of the Royal Łazienki Park has been carried out since the 1960'. An important element of these studies was the analysis of physical and chemical properties of soils as indicators of environmental structure and function. Analyses of results and abundant cartographic material reveal specific spatial distribution of soil types and also their properties. Despite intensive horticultural works, which could change soil properties, particularly by enriching the soils in humus, used mainly to restore degraded earths, there are repeatable sequences of soil types there. Their heterogeneity depends largely on land relief, elevation, slope inclination, type of water management. etc.

This paper encompass the synthesis of these studies. Data from particular soil measurement series were set up for autonomous, transit and subordinated areas (catena method) to determine temporal and spatial variability of the functioning of habitat subjected to human impact. The most important trend observed in the time scale was the relationship between soil properties and parent rock. Field location and the distance from communication routes seem to be more important recently. The study showed that the functionally autonomous parts of the park are most stable areas. That was shown by variability soil indices.

Key words: urban park, indicators, catena, environmental changes, The Royal Łazienki Park

Introduction

Urban green spaces – especially forested urban parks – play an important role in urban habitat which extends far from traditionally understood and socially accepted recreational, educational or aesthetic functions. These areas, despite their more or less man-made origin, form enclaves of semi-natural landscape in highly transformed surrounding. Geological, hydrological, hydro-geological and soil forming processes as well as plant succession may proceed within urban greenery. Under such conditions their ecological function would be strengthened or weakened (Griffith 2011, Hough 1995, LaPaix, Friedman 2010, Sikorski, Jackowiak, Szumacher, 2008, Szumacher, 2006, Szumacher, 2005, Cieszewska, Kaliszuk 2000). That is the reason for the importance of studies aimed at demonstrating their environmental quality and pointing to indispensable functions they play in the urban landscape (Hough 1995, Szulczewska, Kaftan 1996, LaPaix, Friedman 2010, Sikorski, Jackowiak, Szumacher, 2008, Szumacher, 2006, Szumacher, 2005, Cieszewska, Kaliszuk 2000, Wolski et al. 1995, Bolund, Hunhammar, 1999, Gobster 2001, Griffith 2011, Ignatieva, Stewart, Meurk 2011). There are three main questions in such kind of study: 1) whether the urban forested park is natural, quasi-natural or anthropogenic, 2) does field location of the park determine landscape geochemical processes, 3) have park's environmental

conditions been changed over time?
In such selected questions urban soils, can be seen as an indicator of environmental quality, a specific study object, whose inform about the state and directions of above mentioned functional and structural changes within park. Knowledge due the changes taking place in soils may help maintaining or restoring natural functions of open areas (Pavao-Zuckerman 2008, Pavao-Zuckerman, Byrne 2009).
Extensive results from studies on soil properties dealt with as indicators of environmental structure and function showing that the basic factors affecting physical and chemical soil properties (including altered by human impact) are their field location and associated (directly or indirectly) type of surface formations, character of water cycling and air circulation (Jenny, 1980, Kowalkowski et al. 1994, Degórski 2005 and others). Due to specific land relief, which affects matter cycling, the catena can be pointed as a useful and powerful object and method of such investigation (Połynow 1956, Kowalkowski 2000). Its advantage lies in "comprehensive consideration of spatial features since catena shows the neighbourhood of units, their vertical structure and processes acting between them" (Ostaszewska 2002, p. 166). The factors, which determining the specific sequence of soil types within catena, are eluvial-colluvial-illuvial processes. Whose intensity depends on drainage (Komisarek, 2000) and mainly on (Sołtyk, 1995):
• input and output of energy in the near-ground atmospheric layer,
• inflow and outflow of water understood as surface runoff and infiltration,
• input and output of clastic material.
Based on temporally reproducible analyses of soil cover in various field locations one may thus establish at least four aspects (dimensions) of geochemical functioning:
- internal processes deciding upon the structure and processes acting within geo-complex,
- external impacts associated with the effect of neighbouring units which determine spatial dynamics of processes associated with field location,
- external (human) impacts,
- temporal variability of these processes which determine the stability of geochemical functioning within catena.
Taking into account above mentioned functional dependences, from a large dataset the following factors determining soil properties and being indicators of soil-geochemical processes were selected:
1. external factors that determine physical and chemical properties of soils and affect processes within catena:
• parent rock affecting water cycling and physical (permeability, retention, susceptibility to erosion) and chemical (pH, the content of macro- and microelements and others) soil properties (Zawadzki 1999)
• land cover affecting ventilation and absorption of air-born pollutants depending on plant density and height (Millward, Sabir 2011)
• slopes indicating the character and proportions of inputs, transport and accumulation of matter and energy and determining geodynamic functions (Połynow. 1956, Komisarek 2000)
• field location which determines the place of soil within catena and the character of landscape processes (Komisarek 2000, Sołtyk 1995, Ostaszewska 2002)
• distance from communication route which is the main source of pollutants transported to park's area in the near-ground layer (Czarnowska, 1978, Gallagher et al. 2008, Acosta et al. 2009, Marianović et al. 2009, Ajmone-Marsan, Biasioli 2010)
2. internal factors being the derivative of external factors and demonstrating geochemical processes , in these the intensity of human impact in particular field locations:
• humus content (Corg) is an index of equilibration of biogeochemical cycles in a landscape. Under equilibrium, the so-called threshold humus pool remains unchanged and humus quality agrees with the quality of plant habitat. Any changes, particularly a decrease of its content, indicate habitat degradation (Zawadzki 1999, Boratyński, Czuba, Góralski 1988).
• pH (in KCl) gives an information on the buffering of acidifying substances. Based on pH measurements one may predict the rate of worsening of habitat properties and forecast the changes that would occur in subordinate units (e.g. the appearance of mobile forms of heavy metals) (Zawadzki 1999, Boratyński, Czuba, Góralski 1988).

• $CaCO_3$ content is an index of the intensity of transport within catena, in particular – of their transport from autonomous to subordinate units

• Pb content as a measure of human impact and pollutants content, mainly those associated with the city traffic (Czarnowska, 1978, Haase 1998, Martin, Coughtrey 1989, Gallagher et al. 2008, Acosta et al. 2009, Ajmone-Marsan, Biasioli 2010).

The Royal Łazienki Park, functionally located on the range of the plain and valley, is a resting ground for broad and thematically differentiated geo-ecological studies in Warsaw. Detailed environmental studies of the park have been carried out since the 1960' Their aim was to analyse biological structure and to identify and assess habitat functioning meant as proper changes (cyclic, fluctuating and evolutionary changes) in the status of geo-complexes (natural habitats) taking place as a result of matter and energy cycling. They pertained mainly to climatic, biotic and hydrologic functions (Czarnecka 1963, Rutkiewicz, Lipiński 1983, Luniak et al. 1986, Current evaluation …1987, Walszczak 1990, Szumacher 2002a, 2000b, Malinowska, Szumacher 2007). An important element of these studies was the analysis of physical and chemical properties of soils as indicators of environmental structure and function (Dobrzański 1975, Current evaluation … 1987, Malinowska 2003, Faliszewska 2005).

Study site

The Royal Łazienki Park (69,34 ha surface area) is situated in the centre of Warsaw neighbours the Royal Route (Al. Ujazdowskie) leading from Wilanów to Old Town. The route is the main source of pollutants which reach the park's area and alter its habitat quality1 . Western areas of the park (20% of the park) are part of the Warsaw Plain mesoregion, eastern one (80%) belong to the Middle Vistula River Valley. The 20 m escarp descending to the river borders the two parts. It also divides two types of natural landscape: river valley bottom and the periglacial plain (fig. 1). The Royal Łazienki Park is situated mainly on the above-flood terrace of the Vistula River. Only its western part is situated at the plain's edge. Sands of various grain size dominate in the valley part (85.1 – 88.1 m a.s.l.), deluvial material is predominant at the foot of the escarp. Plain part (102 m a.s.l.) is covered by silt on boulder loam (Dobrzański 1975, Current evaluation … 1986).

The study transect (360 m wide and 860 m long) was led in the west-east direction (fig. 1). Its upper, flat part occupies the eluvial zone. This zone directly neighbouring the route of Aleje Ujazdowskie. Is covered by low and rarely vegetation. Hence, It has a dynamic air exchange which is associated with dispersion and rapid removal of pollutants. Soils are built of silt formations, in some places mixed with rubble (down to 0.5 or to 1.5 m) or with brought material (sand, gravel, rubble, organic matter). This has a favourable effect on water and air conditions and on the sorption complex capacity. Soils are often de-calcified unless with rubble admixtures. A characteristic feature of upland soil profiles is the presence of eluvial and illuvial horizon which is the evidence of outwashing (Dobrzański 1975, Current evaluation … 1987).

In the transit zone, slope inclination exceeds 15% in the upper and middle stretches but is less than 5% in the lower ones. Slope is a zone of the substances transport from higher elevated, eluvial areas to superaquatic area. Lower parts of the slope are mildly inclined (less than 5%) while in the upper parts of the slope the inclinations increase to more than 15%. The areas have variable conditions of air circulation associated with land cover. The dynamic air exchange which results in rapid dispersion and removal of pollutants is typical of places overgrown by scarce low vegetation while ventilation is hampered in densely tree covered areas which are characterised by shaded undergrowth, decreased wind velocity, mitigated temperature extremes. Vegetation hampers warming of the ground during day and heat radiation in the night. Soils on the slope and at its foot developed from light and medium loams and from strong loamy sands and have a higher content of clay fraction compared with upland soils. Moreover, sediment layers of a smaller permeability are displaced much shallower. Parts of the transect at the foot of the slope and in the river valley are again flat. Superaquatic

[1]The Royal Łazienki Park is also within the reach of gaseous emissions from the Siekierki Heat and Power Plant situated 5 km to the south-east. Due to relatively small park's area, the concentrations of pollutants do not show spatial variability. Results of bioindication studies with the use of lichens and bark's pH showed the concentrations of sulphur dioxide in the whole area between 150 and 170 mg m-3 (Malinowska 2003).

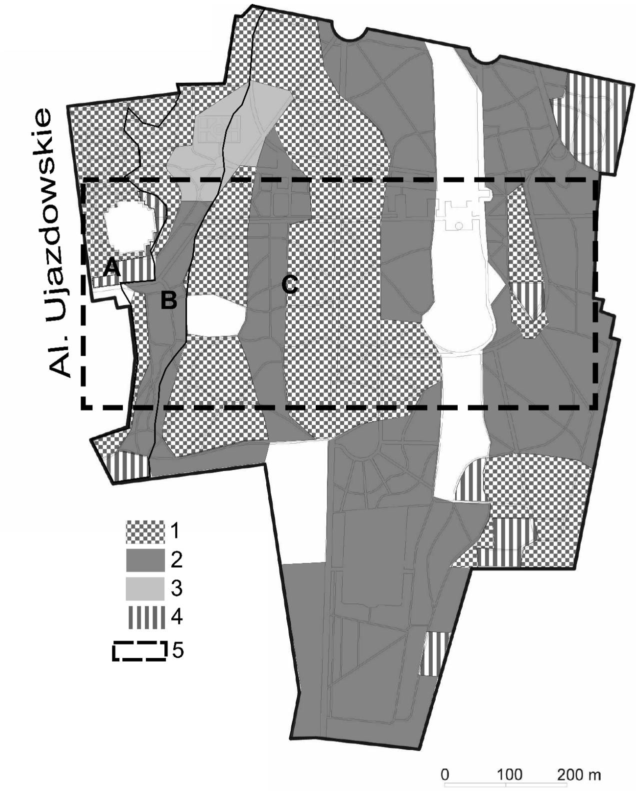


Fig. 1. The Royal Łazienki Park. Landscape-geochemical units: A – plain (eluvial zone), B – slope (transit zone), C- valley (superaquatic zone). Soils: 1 – Cambisols, 2 – Umbrisols, 3 – Dystric Gleysols, 4 – Anthrosols. Border of transect – 5 (on the basis Soil Map. Royal Łazienki Park, 1972, Soil Map. Royal Łazienki Park 1987)

zone (valley) situated in lower part of the transect – in the Vistula River Valley – receive the input of matter from higher elevated slope parts mainly through surface runoff. The grounds covered by tree stands have impeded ventilation and a higher air humidity – areas in the river valley show a tendency to form spots of stagnant air. Wet substratum of a high heat capacity accumulates larger amounts of heat and the vegetation contributes to decreased heat radiation from the ground surface but at the same time prevents from warming on the sunny days. These areas are subjected to the stagnation of pollutants. Within the former oxbow lake and in an area with shallow clay deposits, soils are heavily reduced. Soils in other parts of the valley are mostly built of weak and light loamy sands often mixed with rubble or brought material (gravel, sand, rubble, organic matter). Their water and air conditions are rather good (Current evaluation … 1987, Walszczak 1990).
Natural features of soil cover in the whole catena are transformed by human activity – mineral fertilisation and the enrichment in humus. This may have resulted in potential weakening of the relationships between soil cover properties and other biotic and abiotic landscape elements.

Data and methods

Soils in Łazienki Park were the subject of detailed studies since the 1970'. Thirty four soil profiles were analysed and additional drillings were made in the grid of squares and in dispersed points by Dobrzański (1975) in 1972. A map of soil types (fig. 1), subtypes, kinds and classes was made based on these data. Detailed studies of physical and chemical soil properties and analyses of heavy metals (Zn, Co, Ni, Pb, Mn, Cu) were made in 20 soil profiles. For comparative purposes and in order to follow unfavourable changes in park's habitat, 10 soil profiles from the same places were analysed in 1986 within the interdisciplinary project: „Current evaluation of the hazard to the natural environment of the Łazienki Park and establishment of the directives for the management of the Park". Szumacher (1997, 2005) analysed basic chemical and physical properties of humic horizon (Corg, bulk density, CEC, hydrolytic acidity and CaCO3) taken in 1995/96 and in 2001 from the same sampling points as in 1972. Studies carried out by Ostaszewska (1994) involved only pH of the upper soil layers. Cd, Pb, SO4, CaCO3 and humus were analysed in upper soil layers from selected transects within the bioindication studies in the years 2001-2003 (Malinowska 2003, Faliszewska 2005). Measurements of the soil pH were repeated in 2011 in sampling points from the previous years and in some of them Corg, Pb and CaCO3 were also analysed to assess the changes in soil properties.

Data originated from the surface soil layers analysed in the years 1972 (Dobrzański 1975 - 43 samples), 1986 (Current evaluation… 1987 -10 samples), 2003 (50 samples) and 2011 (45 samples) were set up for eluvial, transit and superaquatic surface to determine temporal and spatial variability of the functioning of habitat subjected to human impact. In order to ensure the comparability of information, data were selected from sampling points situated in similar places and did not undergo intensive cultivation (were not enriched in humus and admixtures of building materials).

The main aim of this studies was to recognize spatial and temporal dynamics of environmental changes under human impact in the park's habitat. Conclusions on the existing relationships, spatial and temporal dynamics and on human impacts were based on statistical analysis, both parametric and non-parametric (correlation, multiple regression, dispersion measures etc.). Discrimination methods (PCA, ANOVA/MANOVA) were used in the first stage which allowed to assess quantitative and qualitative parameters and to eliminate from dataset the data insignificant for further evaluation. Statistical analyses were made with the Statistica v. 7.1 software. Detailed description of the methods can be found in the software manual. Since the analytical methods used to determine the value of involved parameters may differ in precision between study periods, the standardised data in relation to the mean of each analytical series were used instead of actual ones.

During the interpretation of statistical analyses, particularly of variability measures (variance, standard deviation and variability coefficient) it was assumed that the clustering of values around the mean and temporal variability of this status reflect the stability and equilibration of the process – the greater and longer lasting it is the more stable and equilibrated are the landscape-forming processes.

From the available dataset of observations concerned soils properties treated as an indicator of landscape-geochemical changes the following have been chosen: parent rock, land cover, slopes, field location, distance from communication route, Corg, pH (in KCl), CaCO3, Pb. Above mentioned properties analysed as measures illustrated the catena landscape-geochemical processes determined by the neighbourhood of soil-vegetation (habitat) units, their vertical structure and functional and spatial arrangement between them have been used.

Results

Temporal changes in the park habitats

A set of factors affecting landscape functioning markedly changed during the 40-year-long study period (tab. 1). In the beginning (1972), soil pH and the content of humus and carbonates showed the highest, statistically significant, relationships with parent rock and limited (or even missing) effect of field location. These relationships were still observed (though at lesser intensity) in 1986. Since 2003 field location has become the dominating factor. A new factor showing no effect on soil properties before, namely the input of pollutants expressed by the distance from communication route, appeared in this study period (tab. 1). Such correlation is described in most papers on urban soils. Figueiredo et al. (2009) in their studies of soils in 7 parks of Buenos Aires found the highest concentrations of pollutants in parks situated close to the communication routes. The older the parks the higher were these concentrations because of accumulation and immobilization of metals by sorption. Decreased pH may further decline their sorption in soil complexes (Marjanović et al. 2009).

Correlations between soil properties have changed accordingly during the study period. A strong correlation, typical for natural soils, was between pH, carbonates and humus in 1972. Then slowly decreased and finally disappeared in 2011 (tab. 1).

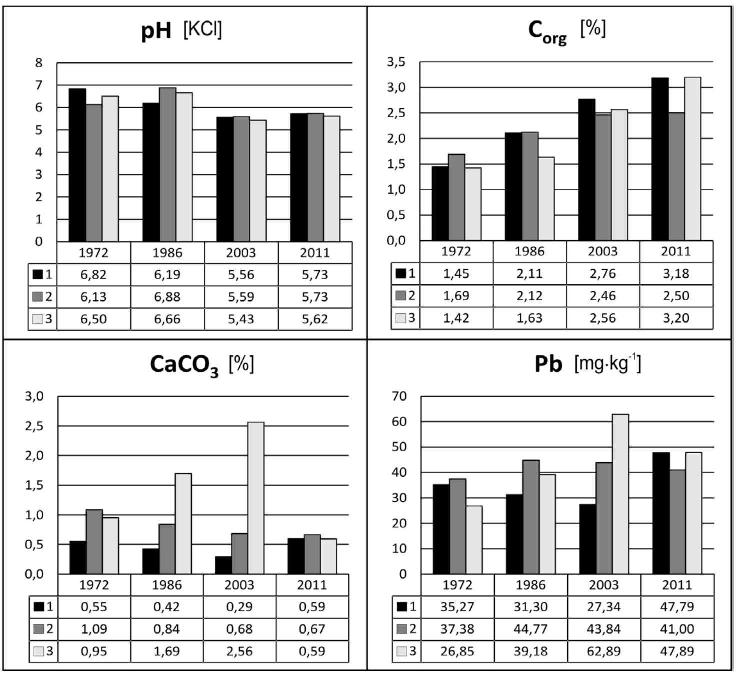
Recorded mean values of pH and humus content did not differ from those found in naturally developed soils (Boratyński et al 1988, Fotyma et al. 1987, Zawadzki 1999). Mean lead concentration (<60 mg·kg-1) did not exceed standards given in „Order of the Minister of Environment on the standards of soil and earth quality" for urban areas. At the same time soil pH and humus content showed the smallest variability (in statistical sense) during the whole study period (fig. 2). These parameters markedly fluctuated in time, nevertheless, they showed a small variability within particular locations (fig. 2). Most values are clustered around the mean (VC ≤ 0.2) which is an evidence for stady state of functioning of these areas, with respect to processes affecting pH and humus content. This could be an effect of stable inputs of gaseous pollutants since the acidifying effect of fulvic acids or other substances not analysed in sampling sites. Concentrations of lead and carbonates were much more variable (0.17 ≤ VCCaCO3 ≤ 1.21; 0.08 ≤ VCPb ≤ 0.51). It may suggests a lack of equilibration between inputs, transport and accumulation of these substances.

Above described type of temporal functioning of soils corresponds to the model of quasi-natural soils which have developed in urban ecosystem under the effect of natural factors (Effland, Pouyat 1997). Far ahead, due to anthropogenic factors (which in the Royal Łazienki Park were activated in the 18th century and intensified in the 20th century), the natural relationships between soil properties slowly declined. Natural processes and soil properties may be restored in these soils providing the "metapedogenic" processes previously were interrupted. Dobrzański already in 1975 described two totally natural soil profiles in central part of the park and emphasised the need of particular protection of such soils.

Spatial differentiation within catena and its geochemical functioning

Finding clearly directional long-term changes (fig. 2) noted in the whole, nearly 40-year-long study period is important in view of the identification of processes taking place within catena (fig. 3). The changes include: a significant decrease of soil pH, linear increase of humus content in all field locations and proceeding, though very slow, loss of calcium carbonate in autonomous, transit and subordinated locations (in 2011). Lead concentrations show distinct inversely proportional relationship between eluvial and superaquatic zone (in transit areas lead concentrations were similar in all measurement series).

The enrichment of soils in lead and carbonates observed in subordinated areas suggests that outwashing of chemical components from autonomous areas under acidic conditions is the dominating process within catena. These areas situated near the source of dust and gaseous emission are susceptible to pollution. They are characterised by the prevalence of atmospheric input (acidifying gaseous substances and dust containing e.g.



pH [KCl]	1972	1986	2003	2011
1	6,82	6,19	5,56	5,73
2	6,13	6,88	5,59	5,73
3	6,50	6,66	5,43	5,62

C_{org} [%]	1972	1986	2003	2011
1	1,45	2,11	2,76	3,18
2	1,69	2,12	2,46	2,50
3	1,42	1,63	2,56	3,20

$CaCO_3$ [%]	1972	1986	2003	2011
1	0,55	0,42	0,29	0,59
2	1,09	0,84	0,68	0,67
3	0,95	1,69	2,56	0,59

Pb [$mg \cdot kg^{-1}$]	1972	1986	2003	2011
1	35,27	31,30	27,34	47,79
2	37,38	44,77	43,84	41,00
3	26,85	39,18	62,89	47,89

Fig. 2. Mean values of chosen soil parameters in 1972, 1986, 2003, 2011 at different field locations:
1 – eluvial zone, 2 – transit zone, 3 – superaquatic zone

Table. 1. Correlations between external and internal factors determining physical and chemical soil condition (Pearson correlation coefficient)

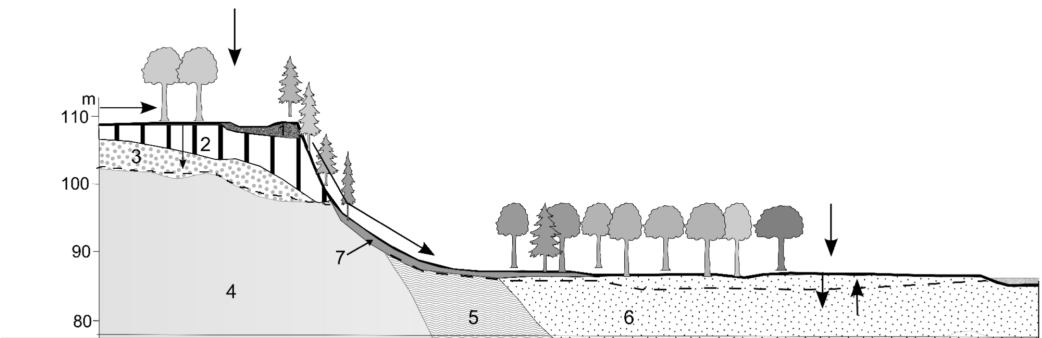
		1972 (n=43) $\alpha_{0,01}{}^{1}=0,395$; $\alpha_{0,05}=0,305$				**1986** (n=10) $\alpha_{0,01}=0,785$; $\alpha_{0,05}=0,635$				**2003** (n=50) $\alpha_{0,01}=0,275$; $\alpha_{0,05}=0,375$				**2011** (n=45) $\alpha_{0,01}=0,295$; $\alpha_{0,05}=0,390$			
		pH KCl)	Corg	$CaCO_3$	Pb	pH KCl)	Corg	$CaCO_3$	Pb	pH KCl)	Corg	$CaCO_3$	Pb	pH KCl)	Corg	$CaCO_3$	Pb
External factors	parent rock	++	+	+	-	++	-	+	+	+	-	-	-	+	-	-	+
	land cover	-	-	-	-	-	-	-	-	+	-	-	-	+	-	-	+
	slopes	+	-	+	-	+	-	-	-	-	-	-	+	-	+	+	+
	field location	+	-	-	-	+	+	+	+	++	+	++	++	++	++	++	++
	distance from route	-	-	-	-	-	-	-	-	+	-	+	+	++	-	++	++
Internal factors	pH (KCl)																
	Corg	++				+				+				-			
	$CaCO_3$	++	+			++	+			+	-			-	-		
	Pb	-	-	-		+	-	+		+	+	+		+	-	-	

Significance level according to Student-t distribution:1% (α0,01) and 5% (α0,05) heavy metals), a lack of side inputs and vertical migration in the substratum.

Carbonates dissolve and heavy metals become more mobile in autonomous areas at pH decreasing due to air-borne pollution from communication route and maybe from the heat and power plant Siekierki. They migrate with water cycle to subordinated areas showing thus the role of this factor in shaping landscape-geochemical processes within catena (fig. 3).

Variability coefficients show that autonomous areas are the most stable parts of a fixed type of functioning within catena. They assumed the lowest values for all analysed soil properties (fig. 4). Transit areas, on the other hand, are characterised by much smaller fluctuations of absolute values of the studied properties (fig. 2). This is because the surface runoff and mass movement are the dominating processes there at a negligible contribution of evapotranspiration and infiltration on sandy slopes. The values of pH and humus content scattered slightly more around the mean as compared with autonomous areas which allows for considering these areas stable in view of the processes that control pH and humus content.

Subordinated areas (lowland part of the park) showed the smallest variability of selected parameters (apart from calcium carbonate) in time which may evidence the stability of this area (Fig. 3). Organic carbon content tends to increase in the river valley. This result may indicate the equilibration of biogeochemical cycles in the landscape. The increment of Corg is an effect of intensive woodland tending works (Szumacher 2010).



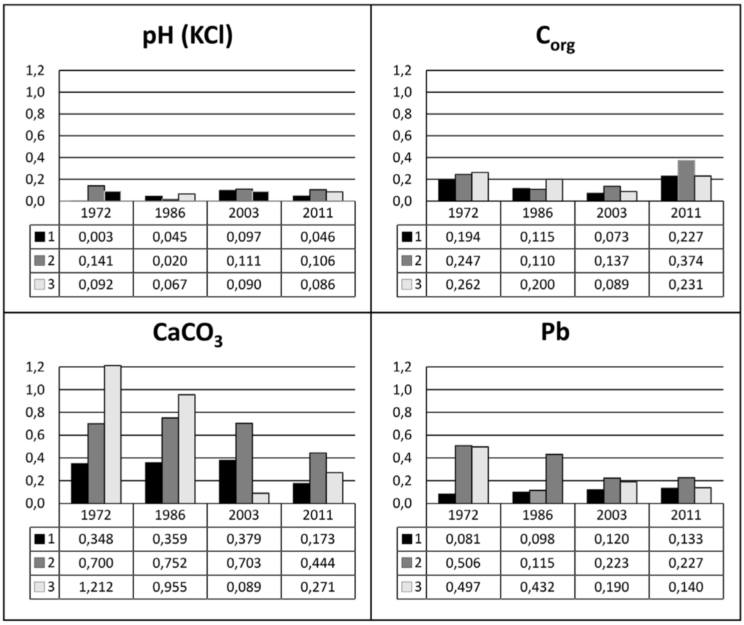
zone		eluvial		transit		superaquatic		
temporary changes	Corg	higher		higher		higher		
	pH	lower		lower		lower		
	$CaCO_3$	stable		lower		changing		
	Pb	higher		higher		higher		
	habitat	stable		stable		stable		
Soils		Cambisols	Anthrosols	C.	Umbrisols	Cambisols	Umbrisols	Cambisols

Fig. 3. Landscape-geochemical caten in the Royal Łazienki Park. 1) artificial material, 2) glacial till, 3) glacial sand, 4) Pliocene clays, 5) alluvial sand +peat/silt, 6) alluvial sand 7) deluvium

Conclusions

Studies made in Royal Łazienki Park allowed for tracing spatial and temporal changes. Analyses of results and abundant cartographic material (Soil Map. Royal Łazienki Park, 1972, Soil Map. Royal Łazienki Park 1987, Map of lead, zinc … 1987, Soil Map of Warsaw 2000) reveal specific spatial distribution of soil types and also their properties. Despite intensive horticultural works, which could change soil properties, particularly by enriching the soils in humus, used mainly to restore degraded earths, there are repeatable sequences of soil types there. Their heterogeneity depends largely on land relief, elevation, slope inclination, type of water management etc. Pearson correlation coefficients showed a clear dichotomy in the course of landscape functioning which resulted in the alteration of given physical and chemical soil properties. It is especially seen in the relationships between parent rock, field location and the properties of the soil cover.

Although this area is under the influence of human activity, it can be classify as quasi-natural. One may thus



pH (KCl)

	1972	1986	2003	2011
1	0,003	0,045	0,097	0,046
2	0,141	0,020	0,111	0,106
3	0,092	0,067	0,090	0,086

C_{org}

	1972	1986	2003	2011
1	0,194	0,115	0,073	0,227
2	0,247	0,110	0,137	0,374
3	0,262	0,200	0,089	0,231

$CaCO_3$

	1972	1986	2003	2011
1	0,348	0,359	0,379	0,173
2	0,700	0,752	0,703	0,444
3	1,212	0,955	0,089	0,271

Pb

	1972	1986	2003	2011
1	0,081	0,098	0,120	0,133
2	0,506	0,115	0,223	0,227
3	0,497	0,432	0,190	0,140

Fig. 4 Differentiation of selected soil parameters analysed in the years 1972, 1986, 2003, 2011 in particular field locations based on the variability coefficient
1 – eluvial plain, 2 – transit zone, 3 – superaquatic zone

conclude that quasi-natural relationships in a landscape give way to anthropogenically determined processes. This park is located within the three kinds of zones (eluvial, transit and superaquatic) which determinate functioning of this area. Field location and the distance from communication routes seem to be more important recently. Eluvial zone of the park is most stable area of a fixed type of functioning. That fact was shown by variability indices – the lowest for all analysed soil properties. The most important trend observed in the time scale was the relationship between soil properties and parent rock.

Obtained results indicate that, despite increasing human impact and abandoned tending of woodlands, park's soils may well play their ecological function thus strengthening the quality of urban ecosystem.

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