

Development of Soil Consumption Driven by Urbanization and Pattern of Built-up Areas in Prague Periphery since the 19th Century

JAN STACHURA¹, TOMÁŠ CHUMAN^{1,2} and LUDĚK ŠEFRNA¹

¹*Department of Physical Geography and Geoecology, Faculty of Science, Charles University in Prague, Prague, Czech Republic;* ²*Czech Geological Survey, Prague, Czech Republic*

Abstract

Stachura J., Chuman T., Šefrna L. (2015): Development of soil consumption driven by urbanization and pattern of built-up areas in Prague periphery since the 19th century. *Soil & Water Res.*, 10: 252–261.

Soil consumption has become a very rapid and intensive process in many European countries, especially around large cities and important highways. The Prague periphery is not an exception. This paper analyses the extent and quality of consumed agricultural land and pattern of built-up areas in selected 22 cadastres in Prague periphery, by using historical maps and orthophotomaps, over four time horizons since the 19th century till 2010. The results show an extensive soil consumption. The average extent of built-up area increased from less than 1% to more than 13% per cadastre. This extensive development caused consumption of high quality soils and changed the pattern of built-up areas from more compact to less compact built-up areas. The average nearest neighbour distance between built-up patches has increased by more than 38%.

Keywords: Czech Republic; land take; quality of soil; soil sealing; urban sprawl

Land use changes due to urbanization are one of the most serious environmental issues that Europe is facing today because the speed of the changes caused by urbanization, their frequency and magnitude increased unprecedentedly in the second half of the 20th century (ANTROP 2000). Urban sprawl, a specific form of urbanization, is the most significant driver of land use changes. Urban sprawl is a phenomenon of spreading extensive forms of built-up areas into city agricultural surroundings (TORRENS & ALBERTI 2000; GAYDA *et al.* 2005) leading to soil consumption (conversion of agricultural land to developed areas) and soil sealing (covering soil with impermeable material e.g. asphalt, concrete).

Many studies (SÝKORA 2002; PAULEIT *et al.* 2005; HAASE 2009; SCALENGHE & MARSAN 2009; CHUMAN & ROMPORTL 2011) have shown that urban sprawl has significant negative impacts on the environment since it affects many ecosystem functions and services, e.g. water infiltration, water retention, habitat suitability, and food production. Many of these functions are

affected due to soil sealing. About 4% of soils have been sealed in the EU, and fertile soils near large agglomerations are often endangered (EEA 2010). In the EU's "Thematic strategy for soil protection" (CEC 2006), soil sealing is considered to be a threat, and national authorities should adopt strategies to limit this phenomenon.

Urban sprawl is a phenomenon experienced by cities across whole Europe. Many studies have focused on urban sprawl in Europe, such as SCATTER (GAYDA *et al.* 2005), MOLAND (KASANKO *et al.* 2006), Circ-Use (Institute for Ecology of Urban Areas 2010) and PLUREL (PLUREL 2010; PAULEIT *et al.* 2013). In the Czech Republic, research has focused on mostly socioeconomic drivers and the consequences of urban sprawl (OUŘEDNÍČEK *et al.* 2008–2014, 2011), or on a specific type of urban sprawl, e.g. development of commercial areas (KOŽELOUH 2010; SPILKOVÁ & ŠEFRNA 2010; CHUMAN & ROMPORTL 2011), both occurring during last two decades at most. Studies focusing on land take (soil consumption, soil sealing)

doi: 10.17221/204/2014-SWR

and the spatial structure of urban development over longer time scales are scarce. Therefore, the main objective of this research was to perform a qualitative and quantitative analysis of soil consumption and of the pattern of built-up areas in the Prague periphery since the 19th century.

An overview of the extent and intensity of urban sprawl in Europe and the Czech Republic. The primary source of data on urban sprawl for many EU countries is the CORINE land cover database. According to this database, land take is most intensive in highly inhabited regions like Benelux or some regions in Germany. Developed areas (artificial surfaces according to CORINE LC nomenclature) covered more than 8% in some NUTS 3 regions in these countries in 2006. The highest increase, of more than 5% of artificial surfaces, was found in southern Europe (Spain, Portugal, and Cyprus) between 2000 and 2006. The increase was much higher (above 20%) at the NUTS 3 region level. By using the “Land take per capita indicator”, Ireland, Spain, Portugal, and the Netherlands had the highest values in the year 2006. However, a comparison of the intensity of land take in these countries from 1990 to 2000 and from 2000 to 2006 showed a declining trend in the EU27 except for Spain. In opposite to that trend, there was an increase in land take intensity in the countries newly associated to the EU such as Romania, Latvia, and Bulgaria.

Land take mainly occurs at the expense of agricultural land. In the Czech Republic, detailed land use and land cover data also show an annual decline of arable land since 1990 (BIČÍK *et al.* 2010; CHUMAN & ROMPORTL 2011; KUPKOVÁ 2011). Data from the period 2000–2010 showed that Czech Republic was losing about 4000 ha of arable land annually (Czech Statistical Office 2013). However, a significant proportion of this arable land loss was not caused by the land take but by the conversion of arable land to grassland and forest land. Built-up areas increased by 80 ha annually from 2000–2010, but when including other artificial surfaces, the annual increase was up to 2000 ha. The proportion of all artificial surfaces was about 12% for periphery districts of Prague in 2011 and about 10.5% for the whole Czech Republic (Czech Statistical Office 2013).

Soil consumption significantly affects both the production and non-production functions of soils and is closely connected with food production and food self-sufficiency (UHEL 2006). High quality soil should be protected for food production, as rapid

soil consumption may endanger the food security and food production for the next generation (CHEN 2007; KIBBLEWAITHE *et al.* 2012). Therefore, not only the quantity, but also the quality of consumed soils should be of primary concern. Surprisingly, on the outskirts of large cities such as Prague there are many examples where soil consumption occurs even on the most fertile soils, despite the fact that this most fertile soil has been protected for centuries to support the food production (SPILKOVÁ & ŠEFRNA 2010). The cost of soil is a crucial factor in soil protection (ROAKES 1996), and the low cost of fertile soils in the Czech Republic has been criticized in materials of the EU (PROKOP *et al.* 2011).

MATERIAL AND METHODS

Cadastral selection. Twenty-two model cadastres were selected on the Prague periphery to analyze the extent and the pattern of built-up areas and quality of built-up soils in the long term. The 22 cadastres set was chosen to cover a maximum soil quality diversity of dominant soil types at a driving distance of up to 20 min from Prague (Figure 1).

Soil cover, soil quality, and built-up areas data acquisition. Soil cover and soil quality were derived from the Evaluated Soil Ecological Unit – ESEU (“BPEJ” in original) database (Research Institute for Soil and Water Conservation, Prague, Czech Republic). Each ESEU represents soils of homogeneous physical and chemical characteristics and productivity (NĚMEČEK *et al.* 1985). Based on physical and chemical properties of soil (mainly pH, cation exchange capacity, basic saturation, soil organic matter content, soil texture, soil water regime) weighted by climate region the quality (productivity) of each ESEU is expressed on a 100 point scale index (NĚMEČEK *et al.* 1985). The area weighted average soil quality index of all ESEU was computed for each selected cadastre and for built-up area in each cadastre. These indexes of the built-up area and of the whole cadastre were put in ratio (times 100) to show whether lower (< 100) or higher (> 100) than average quality soils were consumed.

The extent of built-up areas was acquired for four time horizons. The oldest data show the extent of built-up areas in the 1820s and 1830s and were derived from Imperial Imprints of the Stable Cadastre of Bohemia, a historical cadastre map at a scale 1:2880 provided by the Czech Office for Surveying Mapping and Cadastre and National Archive (hereafter we

Table 1. Pattern indicators

Variable	Units
Built-up patch density (number of patches per km ²)	No./km ²
Border length of built-up areas per km ²	km/km ²
Built-up area (proportion within a cadastre)	%
Nearest neighbour distance (between built-up patches)	m

refer to this time horizon as the 1830s). These maps provide a precise source of information about the landscape, showing the state before industrialization and urbanization (BRŮNA *et al.* 2005; SKOKANOVÁ *et al.* 2012). The maps were georeferenced in ArcGIS software (Esri 2012).

For the second time horizon, built-up areas were derived from maps of the so-called Third Military Mapping at a scale of 1:25 000 produced in the 1870s. In the third and fourth time horizons the extents of built-up areas were derived from orthophotos from the 1950s at scales of 1:18 000–1:26 000 and current orthophotos (year 2010) with a 1 m resolution. We applied on screen vectorization of built-up areas at a view scale of 1:200 with a minimum mapping unit of 15 m². Because of various spatial resolutions of the used datasets we did not do spatial overlays of vector data and used the acquired data only to evalu-

ate the extent and pattern (see Table 1) of built-up areas in selected cadastres.

Data analysis. We used column standardization (MELOUN & MILITKÝ 2004) of the pattern indicators (Table 1) by dividing them by the standard deviation (1).

$$y_{ij} = x_{ij}/s_j \quad (1)$$

where:

y – standardized data

x – original data

s_j – standard deviation

j – column

i – row

To reveal similarities in urban development among the cadastres, we used Euclidean distance and partitioning around medoids (PAM) cluster methods (ANTONIADIS & GENTLEMAN 2003), a robust type of K-mean clustering (NG & HAN 2002). Spearman's correlation coefficients were computed to reveal the relationships among the variables prior to cluster analysis, and highly correlated variables were omitted from the clustering – e.g. the length of the borders of the built-up areas which strongly correlated with the proportion of the built-up areas.

Data processing and analysis were done using R software (The R foundation for statistical computing, 2011; R Studio, 2009–2012) with package "Clue" (HORNÍK & BÖHM 2014).

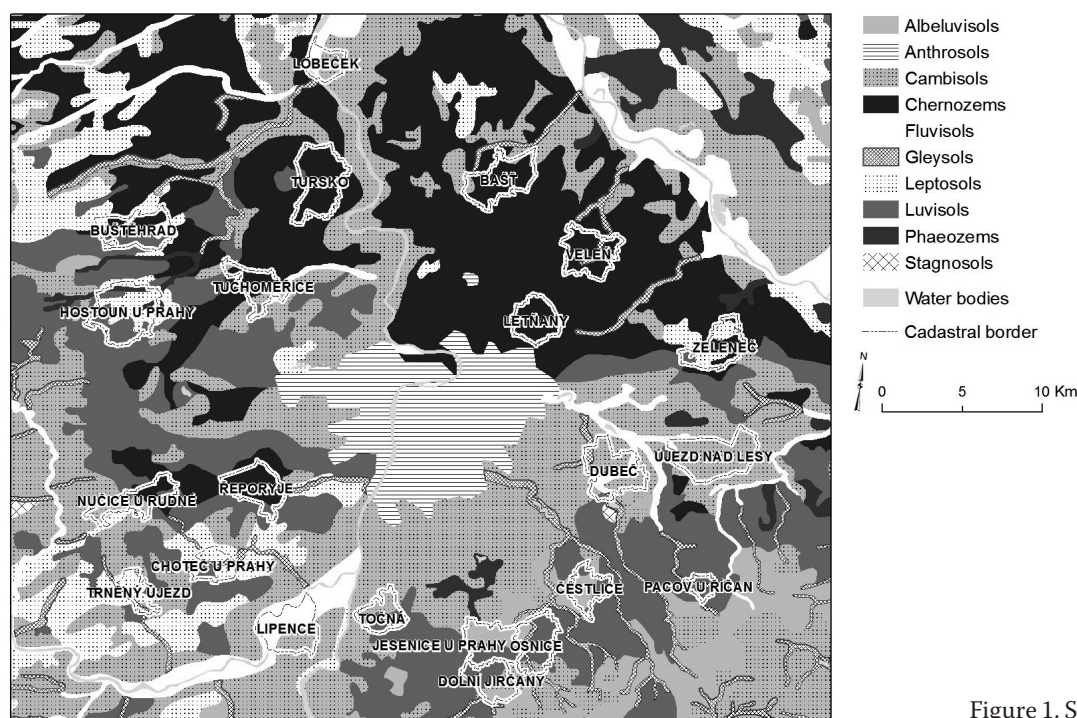


Figure 1. Selected cadastres

doi: 10.17221/204/2014-SWR

ClValid R package (Brock *et al.* 2008) was used to select the optimal number of clusters. Almost 60% of variance among cadastres was explained with 5 clusters using PAM method.

RESULTS

The extent of built-up areas. The average extent of a built-up area increased from less than 1% to more than 13% per cadastre. The extent of built-up areas was very low in the 1830s, reaching only 0.5% of the total cadastre area for all cadastres. The Buštěhrad cadastre was the only exception, with a built up area proportion reaching 0.7% because it was a historical town with a castle. The differences among clusters were negligible (Table 2).

In the 1870s the extent of built-up areas was very similar and no significant expansion occurred. Because of a low spatial resolution of the primary source of data this time horizon gives us only general information, however a significant built-up area expansion should have been recorded. The number of cadastres with a higher proportion of built-up areas increased slightly, but only in the Tuchoměřice and Lobeček cadastres the proportion exceeded 0.5%. In some cadastres a decrease of built-up areas was recorded, presumably due to a lower data resolution.

The cadastres started to diversify in the 1950s. The Buštěhrad cadastre still has had one of the highest proportions of built-up areas, but maximum values have been recorded in cadastres with industrial development such as Letňany and Lobeček. A mixture of residential and commercial development increased the proportions of built-up areas in the Řeporyje and Nučice cadastres. In contrast, the lowest proportion of built-up areas occurred in the Točná cadastre.

The extent of built-up areas continued to increase till 2010. Maximum values were recorded in the industrialized cadastres Letňany and Lobeček (proportion of built-up area > 40%). Other cadastres with proportions between 15 to 20% differed in the form of development. Based on visual orthophotomaps interpretation, enormous commercial urban development was recorded for example in the Čestlice cadastre, while Jesenice cadastre showed mainly residential urban development. In the Řeporyje and Buštěhrad cadastres a mixture of both residential and commercial urban development has continued from the 1950s. The built-up area significantly increased in most cadastres, however, several cadastres, e.g. Točná, Trněný Újezd, and Choteč, did not show intensive development. There the proportion of built-up area remained below 4%.

Pattern of built-up areas. The spatial structure of the built-up areas was described by the length of

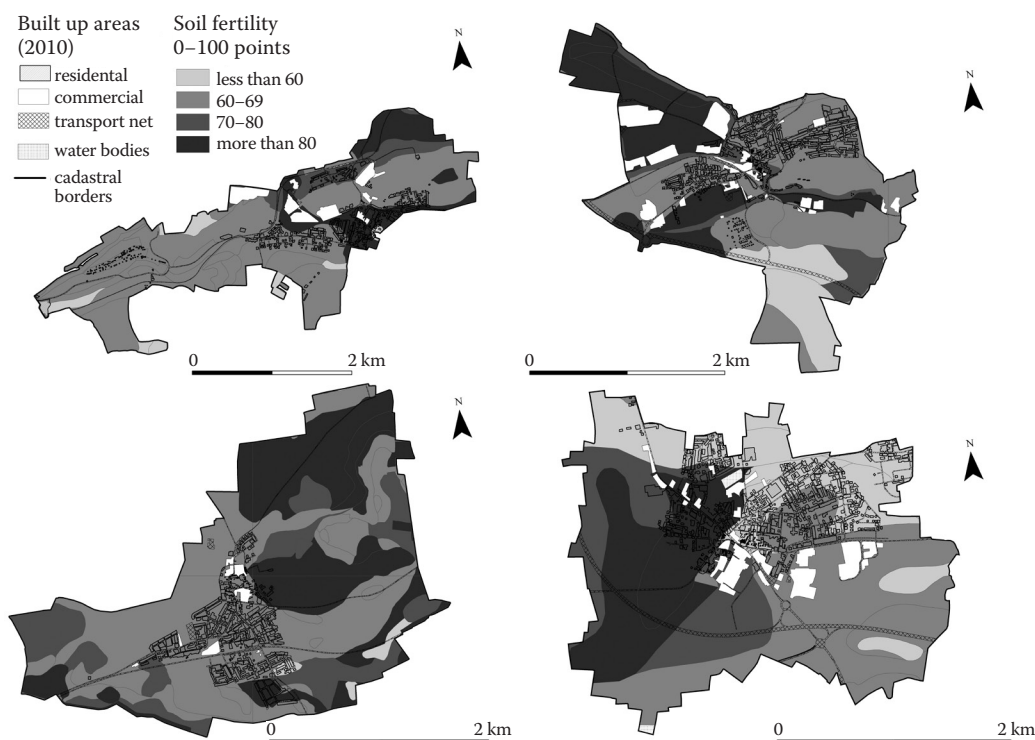


Figure 2. Examples of the development of built-up areas in cadastres Nučice, Řeporyje, Jesenice and Zeleneč

Table 2. Pattern indicator values for selected cadastres in chosen time horizons

Cadastral name	Built-up area (proportion of total cadastral area)				Border length of built-up areas (km/km ²)				Nearest neighbour distance (m)				Built-up patch density (No./km ²)			
	1830s	1870s	1950s	2010	1830s	1870s	1950s	2010	1830s	1870s	1950s	2010	1830s	1870s	1950s	2010
Bašť	0.4	0.3	2.1	6.0	0.8	0.8	2.9	9.1	23.8	23.8	71.7	45.5	11.9	12.3	8.0	29.0
Buštěhrad	0.7	0.8	6.4	18.5	1.4	1.9	9.4	14.5	29.0	29.0	56.4	66.2	19.1	24.0	21.7	23.7
Čestlice	0.4	0.5	4.4	19.8	0.8	1.0	6.7	15.9	32.5	32.5	52.5	57.4	10.9	11.6	8.4	30.6
Doní Jirčany	0.3	0.3	2.5	14.2	0.7	0.7	5.8	17.9	29.9	29.9	47.7	45.0	10.3	11.1	20.2	70.6
Dubeč	0.3	0.4	3.0	8.8	0.9	1.0	5.4	13.6	26.6	26.6	66.6	31.9	14.0	14.2	17.3	75.8
Hostouň u Prahy	0.5	0.4	2.5	3.7	0.9	0.9	4.1	6.6	34.5	34.5	65.8	38.4	10.5	12.5	7.6	25.1
Chotěč u Prahy	0.4	0.3	2.4	2.9	0.9	0.9	5.5	6.3	57.7	57.7	57.2	33.7	12.4	14.0	13.7	31.7
Jesenice	0.5	0.3	3.0	18.1	1.1	0.9	4.9	22.5	41.9	41.9	53.2	40.9	13.6	14.2	11.9	79.2
Letňany	0.5	0.3	10.2	45.6	0.7	0.7	6.1	23.7	25.4	25.4	58.3	71.9	9.5	10.5	23.2	37.8
Lipence	0.4	0.3	3.2	9.2	1.0	1.0	7.7	14.0	28.9	28.9	42.6	37.1	14.5	17.9	36.4	75.0
Lobeč	0.3	0.6	7.5	51.8	0.7	0.9	12.6	24.2	33.6	33.6	48.9	52.0	9.6	9.6	48.1	61.1
Nučice u Rudné	0.3	0.3	6.3	12.8	0.8	0.9	10.8	16.1	26.7	26.7	71.3	43.1	11.6	13.0	19.2	62.3
Osnice	0.2	0.3	2.1	8.8	0.5	0.7	4.1	13.7	36.7	36.7	49.6	40.2	6.8	9.8	10.9	55.4
Pacov u Říčan	0.5	0.5	4.5	10.9	1.4	1.6	10.0	21.9	24.9	24.9	51.1	33.6	26.4	28.6	40.7	127.2
Řeporyje	0.3	0.3	5.6	18.8	0.8	0.9	9.8	21.1	28.2	28.2	46.2	38.2	10.9	13.2	29.6	78.0
Točná	0.1	0.2	1.2	3.8	0.5	0.5	3.2	16.1	28.6	28.6	52.4	36.7	7.6	9.1	10.4	45.3
Trněný Újezd	0.2	0.2	2.7	2.2	0.6	0.6	6.3	4.9	24.1	24.1	165.6	54.7	8.6	8.9	5.4	11.0
Tuchoměřice	0.5	0.7	2.6	4.9	1.0	1.5	4.8	8.4	31.9	31.9	75.3	36.8	13.3	16.9	11.1	42.3
Tursko	0.4	0.3	2.3	4.2	0.8	0.7	3.8	6.5	30.2	30.2	72.1	34.5	9.4	10.1	6.1	19.9
Újezd nad Lesy	0.1	0.1	3.4	16.5	0.3	0.3	6.1	26.4	38.6	38.6	46.6	35.6	3.8	5.0	41.5	128.0
Veleň	0.4	0.3	2.6	5.1	0.9	0.8	4.6	7.2	27.0	27.0	44.0	37.3	12.2	11.9	13.1	32.1
Zeleneč	0.3	0.4	4.0	9.4	0.8	0.9	7.1	14.3	24.5	24.5	47.4	39.5	11.3	10.3	20.7	45.8

doi: 10.17221/204/2014-SWR

borders, density of patches, and the nearest neighbour distances (Table 2). This extensive development changed the pattern of built-up areas from more compact to less compact built-up areas. An average nearest neighbour distance between built-up patches was increased by more than 38%.

The nearest neighbour distances and density of built-up patches were very variable over all analyzed time horizons. In some cadastres the nearest neighbour distance increased between the 1830s and 1950s but decreased till 2010, reflecting the sprawl of urban development in the first phase and infilling in the second phase. The continuously increasing value of the nearest neighbour distances in other cadastres, e.g. Letňany, Lobeček, Buštěhrad, and Čestlice (Table 3), show a continuous sprawl of the built-up areas.

In general, the length of the borders strongly correlated with the extent of built-up areas (Table 2). However, some cadastres, e.g. Újezd nad Lesy and

Lipence, showed very high values of border length in 2010 despite the proportion of built-up areas being relatively low. This was mainly due to the presence of dispersed recreational properties. Edge length density (Table 2) showed significant changes over the whole study period, increasing from values less than 1 km/km² up to an average of almost 15 km/km².

There were also significant changes in the density of patches (Table 2). This indicator increased from 11 patches per km² per cadastre on average in the 1830s up to 54 patches on average per km² per cadastre in 2010; however, the variability among cadastres was high, ranging from 10 to more than 100 patches per 1 km² per cadastre in 2010. This variable differentiated the set of cadastres mainly in the two last time periods (the 1950s and 2010). The highest values of patch density reflected the development of dispersed recreational properties (e.g. Újezd nad Lesy, Pacov u Říčan, Lipence), high

Table 3. Extent of top quality soil and area weighted average soil quality in the set of 22 cadastres

Cadastre name	Weighted average soil quality index	Extent of top quality soil – total area	Extent of consumed top quality soil
		(ha)	
Bašť	83.6	377.3	27.7
Buštěhrad	77.7	557.8	13.8
Čestlice	60.6	154.7	7.8
Dolní Jirčany	59.8	231.3	20.0
Dubeč	64.7	38.9	0.1
Hostouň u Prahy	71.3	212.5	30.4
Choteč u Prahy	57.7	20.7	0.0
Jesenice	72.0	393.2	51.7
Letňany	88.0	549.2	254.2
Lipence	61.9	304.6	18.1
Lobeček	44.5	49.0	5.2
Nučice u Rudné	68.2	136.7	36.7
Osnice	62.0	422.5	39.5
Pacov u Říčan	63.6	106.4	11.2
Řeporyje	74.7	148.4	29.2
Točná	49.8	110.6	9.5
Trněný Újezd	54.6	15.4	0.1
Tuchoměřice	69.4	274.5	7.2
Tursko	81.6	733.9	36.6
Újezd nad Lesy	66.9	0.0	–
Veleň	87.8	628.8	34.8
Zeleneč	81.1	240.0	3.7

Table 4. Soil quality index ratio; the ratio of area weighted average soil quality index for built-up area and area weighted average soil quality index of the whole cadastre times 100 to show whether lower (< 100) or higher (> 100) than average quality soils were consumed

Cadastre name	1830s	1870s	1950s	2010
Bašť	105	106	105	101
Buštěhrad	107	109	101	103
Čestlice	93	89	100	93
Doní Jirčany	98	91	96	89
Dubeč	95	92	99	98
Hostouň u Prahy	91	97	96	98
Choteč u Prahy	71	76	82	82
Jesenice	101	103	104	99
Letňany	100	100	100	100
Lipence	114	95	92	93
Lobeček	128	135	103	92
Nučice u Rudné	121	122	108	108
Osnice	98	93	96	100
Pacov u Říčan	98	102	100	102
Řeporyje	99	96	99	102
Točná	121	120	119	118
Trněný Újezd	119	118	107	107
Tuchoměřice	81	90	90	92
Tursko	103	103	102	103
Újezd nad Lesy	92	93	99	98
Veleň	101	101	101	101
Zeleneč	93	93	94	95

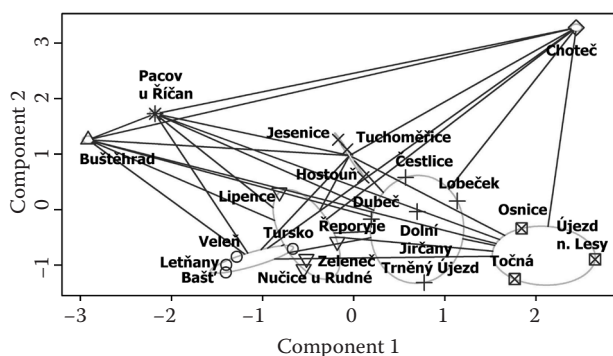


Figure 3. Cluster plot from the 1830s (two components explain 81.5% of the object variability)

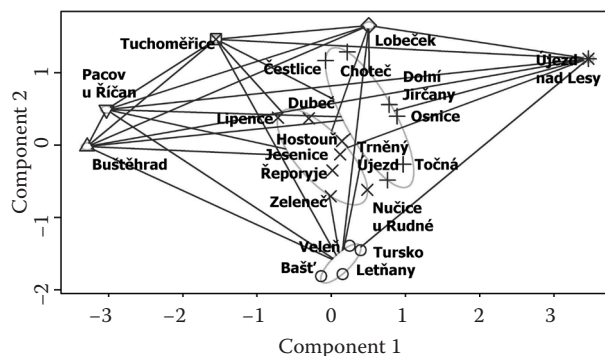


Figure 4. Cluster plot from the 1870s (two components explain 72.5% of the object variability)

values were found in areas with massive residential developments (e.g. cadastres Jesenice, Řeporyje), and low values were typical for cadastres with large commercial areas (e.g. cadastres Letňany, Čestlice).

Quality of soils in built up areas. The extensive development caused a consumption of high quality soils. The top quality, most fertile soils of the Czech Republic occur in the north and north-east parts of the Prague periphery in the cadastres Letňany, Veleň, Bašť, and Tursko on loess Quaternary substrates, however, over 11% (637 ha) of them have been converted to built-up area (Table 3).

The ratio of the area weighted average soil quality index of the built-up area in each cadastre and the area weighted average soil quality index of the whole cadastre showed that soils of predominantly better than average quality within each cadastre were taken (Table 4, Figure 2). This happened even in the past. Generally, in more than one third of the cadastres urban expansion into agricultural surroundings has led to the consumption of above-average quality soils. A different development of built up areas, presumably reflecting different territorial planning attitudes, is

shown in Figure 2. In the Zeleněč cadastre, the most fertile soils were protected. Opposite to that, top quality soils were extensively taken near the Prague ring road in cadastres in the southern part of Prague (Figure 2, Tables 3 and 4).

Similarities and differences in urban development among cadastres. Clustering was based on parameters listed in Table 1 and the cadastral area weighted average soil quality index. The analysis showed the increasing role of pattern of built-up areas in clustering. In the first and second time horizons the clusters were defined mainly by soil quality, because the extent of built-up area was quite similar among cadastres (Figures 3 and 4). Some cadastres were separated due to their slightly higher proportion of built-up areas, less compact built-up areas, and the high density of patches (Figure 3). The compactness of built-up area was influenced for example by the presence of mills and sawmills in some cadastres (e.g. Choteč and Újezd nad Lesy). Since 1950s the similarities among clusters have predominantly been based on the extent of the built-up area and its pattern (Figures 5 and 6), however the clustering has remained sensitive to soil quality.

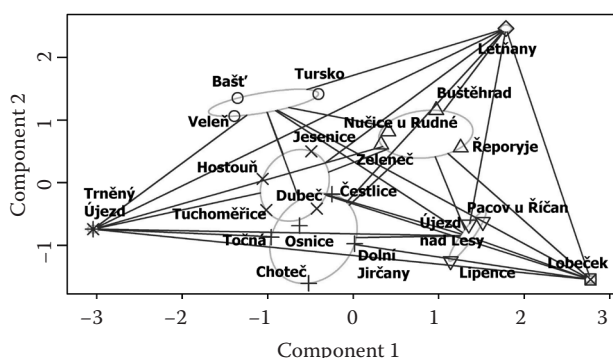


Figure 5. The 1950s cluster plot (two components explain 72.6% of the object variability)

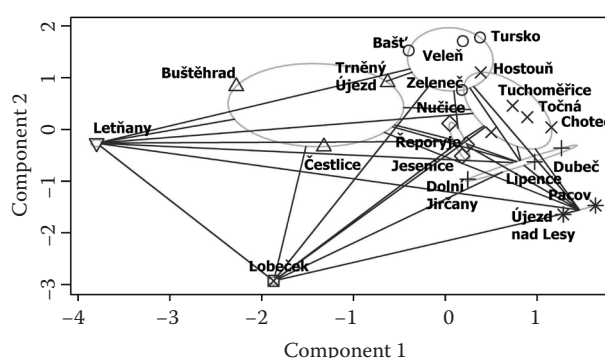


Figure 6. The current orphotomap (2010) cluster plot (two components explain 75.2% of the object variability)

DISCUSSION

Our research into the soil consumption and pattern of built-up areas in the Prague periphery since the 19th century driven by urban development in selected cadastres has resulted in a new empirical knowledge. The average extent of built-up areas increased from less than 0.5% in the 1830s to more than 13% in 2010. In some cadastres the proportion of built-up area reached 50% in 2010. The intensive development of urban areas has been studied elsewhere in Europe and other countries in the USA or Asia (IMHOFF *et al.* 1997; UHEL 2006; ZHANG *et al.* 2007; SALVATI 2013; XIAO *et al.* 2013) and it was proved that sprawling urban areas tend to consume the best agricultural lands (NIZEYIMANA *et al.* 2001; IMHOFF *et al.* 2003; UHEL 2006; SALVATI *et al.* 2013), forcing agriculture to move to less productive areas. Results of this study are in line with published research. In nearly half of the selected cadastres the built-up areas consumed high quality soils (more than 70 points). The quality of the consumed soils was increasing in nearly half of the cadastres between time horizons. Only in 9 out of 22 cadastres the built-up areas expansion avoided the above-average quality soils. In most of the cadastres, sprawling consumed the best quality soils within the cadastre and even some best quality soils nationwide. This was the case of e.g. the Letňany cadastre, where there was no soil of lower quality available for development. Generally, the cadastres along the newly built Prague ring road (Jesenice, Osnice) experienced the most intensive development on protected soils. This implies that favourable logistics positions put high pressure on fertile and even protected soils. In such a case local territorial planning should play a crucial role in effective soil protection. CONWAY and LATHROP (2005) and PICHLER-MILANOVIĆ (2007) suggested that fertile soil needs to be distinguish at the local level and then it can be effectively protected at higher administrative levels. The building up of high quality soils should be avoided, as these soils perform several crucial functions which make them environmentally, economically, and socially important.

An example of a strong protection of the best quality soils is in Slovakia, where they are protected by very high compensation payments for withdrawal of land from the agricultural land resources. For comparison, compensation payments for withdrawal of one hectare of the best quality soil is about 52 000 € in the Czech Republic whereas 200 000 € in Slovakia (Act No. 220

2004 Coll.). On the other hand, only about one fifth of the agricultural soil resources is protected by such high compensation payments in Slovakia (PROKOP *et al.* 2011). Lower payments make soil protection in the Czech Republic very difficult, but the most effective tool for soil protection is territory planning. Territory planning should be an integrative process of natural resource and landscape protection and urban development (SCHETKE *et al.* 2012).

CONCLUSION

The results point to the extensive development of built-up areas that caused consumption of high quality soils and changed the pattern of built-up areas from more to less compact. The process of spreading urban areas into agriculture landscape is an inherent process of town/city development and Prague periphery belongs to the most exposed regions in the Czech Republic, however the building up of high quality soil should be avoided to maintain its crucial functions and services.

Acknowledgements. This research was supported by the Grant No. SVV-244-267-202 (Department of Physical Geography and Geoecology, Faculty of Science, Charles University in Prague) and by the institutional resources of the Ministry of Education, Youth and Sports of the Czech Republic for the support of science and research. We also greatly thank all the institutions providing us with data, namely the National Archives, the Research Institute for Soil and Water Conservation, and the Research Institute of Sylva Tarouca for Landscape and Ornamental Gardening.

References

- Antoniadis A., Gentleman R. (2003): Lab 5: Cluster Analysis using R and Bioconductor. Milano. Available at <https://www.bioconductor.org/help/course-materials/2003/Milan/PDF/Lab5.pdf>
- Antrop M. (2000): Background concepts for integrated landscape analysis. *Agriculture, Ecosystems and Environment*, 77: 17–28.
- Bičík I. *et al.* (2010): Development of land-use in Czechia. Prague, Czech Geographical Society: 47–54. (in Czech)
- Brock G., Pihur V., Datta S., Datta S. (2008): clValid: an R package for cluster validation. *Journal of Statistical Software*, 25: 1–22.
- Brůna V., Křováková K., Nedbal V. (2005): Stabile Cadaster as a source of information of landscape. *Historická geografie*, 33: 397–409. (in Czech)

- CEC (2006): Thematic Strategy for Soil Protection. Brusel. Available at <http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52006DC0231&from=EN>
- Chen J. (2007): Rapid urbanization in China: A real challenge to soil protection and food security. *Catena*, 69: 1–15.
- Chuman T., Romportl D. (2011): Commercial suburbanization. In: Ouředníček M., Temelová J., Pospíšilová L. (eds): *Atlas of Socio-spatial Differentiation of the Czech Republic*. Prague, Karolinum.
- Conway T.M., Lathrop R.G. (2005): Alternative land use regulations and environmental impacts: assessing future land use in an urbanizing watershed. *Landscape and Urban Planning*, 71: 1–15.
- Czech Statistical Office (2013): Public Municipality Database. Available at <https://vdb.czso.cz/mos/> (accessed June 12, 2013).
- EEA (2010): The European Environment State and Outlook: Soil. Available at www.eea.europa.eu/soer/europe/soil/download (accessed June 12, 2013).
- Esri (2012): ArcGIS Ver. 10.1. Redwood, Esri. Retrieved from CD-ROM
- Gayda S. *et al.* (2005): SCATTER: Sprawling Cities and Transport: from Evaluation to Recommendations [Final Report.] Centre for Advanced Spatial Analysis, University College London, London.
- Haase D. (2009): Effects of urbanisation on the water balance – A long-term trajectory. *Environmental Impact Assessment Review*, 29: 211–219.
- Hornik K., Böhm W. (2014): Package “Clue”. Available at <https://cran.r-project.org/web/packages/clue/clue.pdf> (accessed Dec 4, 2014).
- Imhoff M. *et al.* (1997): Using nighttime DMSP/OLS images of city lights to estimate the impact of urban land use on soil resources in the United States. *Remote Sensing of Environment*, 59: 105–117.
- Imhoff M.L., Lawrence W.T., Stutzer D., Elvidge C. (2003): Assessing the Impact of Urban Sprawl on Soil Resources in the United States Using Nighttime “City Lights” Satellite Images and Digital Soils Maps. Available at <http://landcover.usgs.gov/luhna/chap3.php> (accessed Feb 2, 2014).
- Institute for Ecology of Urban Areas (2010): CircUse. Available at <http://www.circuse.eu> (accessed Mar 2, 2012).
- Kasanko M., Barredo J.I., Lavallo C., McCormick N., Demicheli L., Sagris V., Brezger A. (2006): Are European cities becoming dispersed? *Landscape and Urban Planning*, 77: 111–130.
- Kibblewhite M.G., Miko L., Montanarella L. (2012): Legal frameworks for soil protection: current development and technical information requirements. *Current Opinion in Environmental Sustainability*, 4: 573–577.
- Koželouh J. (2010): Environmental Impacts of Spatial Expansion of Large Scale Retail in the Czech Republic in 2003–2009, Research Results. Brno, Nezávislé sociálně ekologické hnutí – Nesehnutí. Available at <http://hyper.cz/soubory/vyzkum%202003-2009.pdf> (in Czech)
- Kupková L. (2011): Land-use. In: Ouředníček M., Temelová J., Pospíšilová L. (eds): *Atlas of Socio-spatial Differentiation of the Czech Republic*. Prague, Karolinum.
- Meloun M., Militký J. (2004): Statistical Analysis of Experimental Data. Praha, Academia. (in Czech)
- Němeček J., Mašát K., Džatko M. (1985): System of Point Valuation of Productivity of BPEJ. Prague, RISWC. (in Czech)
- Ng R.T., Han J. (2002): CLARANS: a method for clustering objects for spatial data mining. *IEEE Transactions on Knowledge and Data Engineering*, 14: 1003–1016.
- Nizeyimana E.L., Petersen G.W., Imhoff M.L., Sinclair H.R., Waltman S.W., Reed-Margaret D.S., Russo J.M. (2001): Assessing the impact of land conversion to urban use on soils with different productivity levels in the USA. *Soil Science Society of America Journal*, 65: 391.
- Ouředníček M. *et al.* (2008–2014): Suburbanization – Czech Republic. Available at <http://www.suburbanizace.cz> (accessed Feb 10, 2013). (in Czech)
- Ouředníček M., Temelová J., Pospíšilová L. (eds) (2011): *Atlas of Socio-spatial Differentiation of the Czech Republic*. Prague, Karolinum.
- Pauleit S., Ennos R., Golding Y. (2005): Modelling the environmental impacts of urban land use and land cover change—a study in Merseyside, UK. *Landscape and Urban Planning*, 71: 295–310.
- Pauleit S., Bell S., Aalbers C., Nielsen T.A.S. (eds) (2013): *Peri-urban Features: Scenarios and Models for Land Use Change in Europe*. Heidelberg, Springer.
- Pichler-Milanović N. (2007): European urban sprawl: sustainability, cultures of (anti) urbanism and “hybrid cityscapes”. *Dela*, 27: 101–133.
- Plurel (2010): Rural – Urban Regions and Peri-urbanisation in Europe: Towards a European Policy to Sustain Urban-Rural Futures. Copenhagen. Available at http://www.plurel.net/images/Peri_Urbanisation_in_Europe_print-version.pdf
- Prokop G., Jobstmann H., Schönbauer A. (2011): Overview of best practices for limiting soil sealing and mitigating its effects in EU-27. *European Communities*, 227. Luxembourg, Publications Office.
- R foundation for statistical computing (2011): R version 2.13.2. Available at <http://mirrors.nic.cz/R/> (accessed July 30, 2013).
- R Studio (2009–2012): RStudio. Available at <http://www.rstudio.com> (accessed July 30, 2013).

doi: 10.17221/204/2014-SWR

- Roakes S.L. (1996): Reconsidering land value taxation. *Land Use Policy*, 13: 261–272.
- Roose A., Kull A., Gauk M., Tali T. (2013): Land use policy shocks in the post-communist urban fringe: A case study of Estonia. *Land Use Policy*, 30: 76–83.
- Salvati L. (2013): Monitoring high-quality soil consumption driven by urban pressure in a growing city (Rome, Italy). *Cities*, 31: 349–356.
- Salvati L., Sateriano A., Bajocco S. (2013): To grow or to sprawl? Land cover relationships in a Mediterranean city region and implications for land use management. *Cities*, 30: 113–121.
- Scalenghe R., Marsan F.A. (2009): The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*, 90: 1–10.
- Schetke S., Haase D., Köttler T. (2012): Towards sustainable settlement growth: A new multi-criteria assessment for implementing environmental targets into strategic urban planning. *Environmental Impact Assessment Review*, 32: 195–210.
- Skokanová H., Havlíček M., Borovec R., Demek J., Eremiášová R., Chrudina Z., Svoboda J. (2012): Development of land use and main land use change processes in the period 1836–2006: case study in the Czech Republic. *Journal of Maps*, 8: 88–96.
- Spilková J., Šefrna L. (2010): Uncoordinated new retail development and its impact on land use and soils: A pilot study on the urban fringe of Prague, Czech Republic. *Landscape and Urban Planning*, 94: 141–148.
- Sýkora L. (ed.) (2002): Suburbanization and its Consequences. Prague, Ústav pro ekopolitiku. (in Czech)
- Torrens P.M., Alberti M. (2000): Measuring Sprawl. CASA Working Paper 27. Centre for Advanced Spatial Analysis, University College London, London.
- Uhel R. (ed.) (2006): Urban Sprawl in Europe: the Ignored Challenge. EAA Report No.10/2006, Copenhagen, European Environment Agency.
- Xiao R., Su S., Zhang Z., Qi J., Jiang D., Wu J. (2013): Dynamics of soil sealing and soil landscape patterns under rapid urbanization. *Catena*, 109: 1–12.
- Zhang X., Chen J., Tan M., Sun Y. (2007): Assessing the impact of urban sprawl on soil resources of Nanjing city using satellite images and digital soil databases. *Catena*, 69: 16–30.

Received for publication September 9, 2014

Accepted after corrections April 21, 2015

Corresponding author:

Dr. TOMÁŠ CHUMAN, Ph.D., Univerzita Karlova v Praze, Přírodovědecká fakulta, Katedra fyzické geografie a geoekologie, Albertov 6, 128 43 Praha 2, Česká republika; e-mail: tomas.chuman@natur.cuni.cz