Land use change analysis for assessment of soil protection efficiency in urban area – URBAN SMS project

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Abstract. The objective of the presented work was to conduct an ex-post analysis of land use change in Wroclaw city, Poland, as a response to the soil protection regulations. The assessment that was a part of Urban Soil Management Strategy (URBAN-SMS) project involved development of land use change maps based on the satellite image data, analysis of land use change trends within 15 years period and subsequent assessment of valuable soils' consumption for urban expansion as an indicator of soil protection efficiency. Most of new transitions into sealed area took place on arable and semi-natural lands. Despite the fee payment instrument, existing within the period under analysis, the most valuable soils were not sufficiently protected. It can be partly explained by the spatial distribution of the best soils.

Keywords: land use, satellite image, soil sealing, soil protection

1. Introduction

Urbanization can be considered as a pressure on landscape reducing its buffering capacity and resistance to degradation (Antrop, 2004). Evaluation of these pressures is fundamental for development of strategies for protection of soils and soil functions. Sealing is one of threats for agricultural soils identified in the framework of Strategy for Soil Protection (COM231, 2006). The sealing process may limit performance of soil functions (retention, production, filtering, biodiversity, etc.) and accelerate other soil threats such as decline in organic matter, contamination, floods, compaction (Stuczynski, 2007). There is increasing interest in determining or modeling the land use change magnitude and its environmental consequences (Pauleit et al., 2005; Rounsevell et al., 2006; Veerburg et al., 2006; Stathis et al., 2010).

The objective of the presented work was to conduct an ex-post analysis of land use change in Wroclaw city, Poland, as a response to the soil protection regulations. It is essential to understand what is the rate and pattern of changes in land use and how these changes, especially soil sealing, affect the overall

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performance of the soil function within the city area. Such an analysis is thought to raise awareness on trends of soil consumption within urban development process and provide information on effectiveness of the soil protection measures. It must be noted that soils differ in properties and, thus, ability to fulfill such functions as retention, biodiversity, filtering, crop productivity.

2. Methodology and Data

The conceptual framework of the analysis of loss of high quality soils in the test area is presented in Figure 1. It involved development of land use change maps based on the satellite image data, analysis of land use change trends within 15 years period and subsequent assessment of valuable soils' consumption for urban expansion as an indicator of soil protection efficiency.

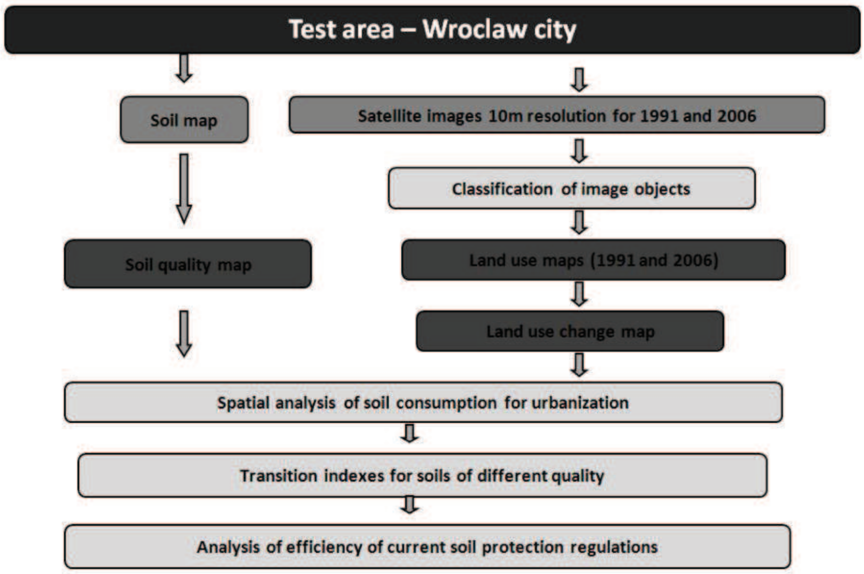

Figure 1. The concept of soil protection efficiency analysis in test areas

2.1. Satellite Images

Satellite images of 10-meter resolution were gathered from SPOT databases. The images represented two periods in order to study land use changes within 15 year timeframe – the black/white photo was captured in 1991 whereas the color photo was taken in 2006 period. The B&W SPOT image is monospectral, color photo is a combination of 4 bands of different wavelengths (0.5-0.59, 0.61-0.68, 0,78-0.89, 1.58-1.75 µm).

2.2. Soil Map

Soil–agricultural map of Wroclaw region in scale 1:25000 was used for Wroclaw case study. Soil valorization system in Poland involves soil suitability units at the range 1-14 for arable lands and 1z-3z for grasslands. This classification basically reflects productivity potential of the soil (suitability to produce certain crops) and the units were delineated based on various soil properties as well as climatic conditions, water conditions and slope. The soil suitability units generally well describe other soil functions such as water retention, buffering capacity or biodiversity. The classes were grouped into high, medium and low quality soils (either from perspective of production function, ecosystem function, buffering, retention etc.). Units 1, 2, 4, 1z were classified as high quality soils, units 3, 5, 8, 2z as medium, while units 6, 7, 9, 14, 3z and barren lands as low quality soils.

2.3. Land Use Change Analysis

Land use maps of 10-meter resolution were produced for the two periods through classification of the satellite images (Fig.2) in Definiens Professional software. Process of land use map development in this software basically consists with two major steps: segmentation and classification. The satellite image is represented by 10mx10m pixels described by spectral information (reflectance data at various wavelengths). Segmentation phase is a process based the fact that land use types (e.g. built up area, forest, water) posses different spectral information. Segmentation delineates spectrally homogenous areas – the segmentation algorithms are used to subdivide the entire image represented by the pixel level domain or specific image objects from other domains into smaller image objects (groups of pixels).

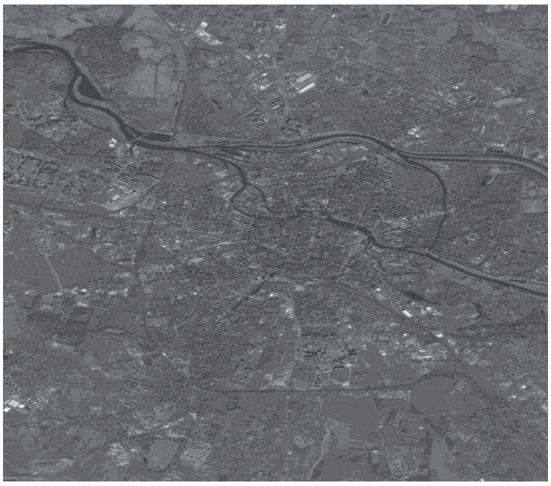

Figure 2. The SPOT satellite image used for development of land use maps.

The classification is a procedure that associates image objects with an appropriate land use class labeled by a name and a color. After careful manual revision of the classification using all available spatial information the obtained final layers were used as land use maps of the pilot area (Fig. 3).

The land use maps contained 13 different land use types: continuous residential areas; commercial and industrial areas; green recreation areas (parks); airports; sport and leisure facilities (with generally impermeable or reconstructed surfaces with

limited performance of soil functions – e.g. stadiums, tennis courts); dump and mineral extraction sites; arable lands; grasslands (pastures and meadows); forests; semi-natural areas (covered by shrubs, trees, not used by agriculture); discontinuous residential areas (residential area with dispersed buildings, still can fulfill some soil functions since most of surface is unsealed); water bodies; transport facilities.
The land use change information for the analyzed area was produced through comparison of land use layers derived for different periods.

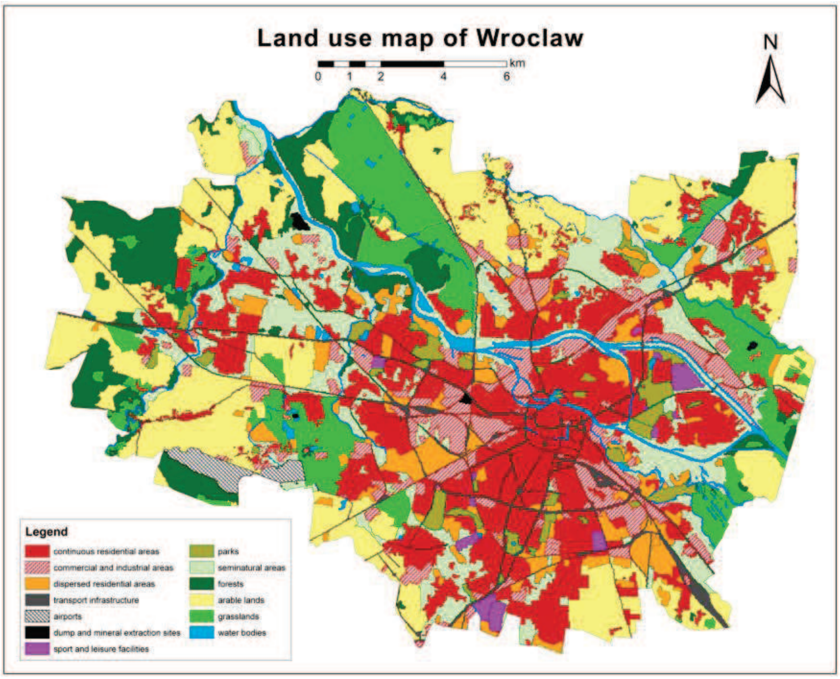

Figure 3. Land use map of Wroclaw for 2006

2.4. Approach for Analysis of Soil Protection Efficiency

The information on land use change was superimposed on the map characterizing soil quality in order to detect to what extend the urbanization took place on valuable soils. The new sealed area, reflecting the built up sprawl of last 15 years, consisted with expansion of the following land use classes: continuous residential area, commercial/industrial area and transport facilities. The soils under these new land use types fully lost their environmental functions.

In order to assess what is the scale of consuming valuable soils by urban sprawl, the transition index was used. It reflects the intensity of land use flows in the context of soil quality [Stuczynski, 2007].

Transition index (TI) = percent of soil class “n” in new built area/percent of soil class “n” in whole soil area

Looking at land use stocks and flows occurring on soils belonging to different quality classes, it is difficult to make a straightforward assessment whether the observed land use change is equally distributed among soil quality classes since the contribution of e.g. soils of high productivity or high water retention potential to the total soil cover may vary greatly between regions or parts of the city (Stuczynski, 2007). Therefore the size (measured in hectares) of change on soils of certain characteristics is not a good indicator if these soils are preferentially taken by urbanization.

Interpreting the transition index is straightforward – for example, index value of 2 for a flow on a given soil class (e.g. high quality soils) means that within changed land the share of this class is twice as high as in the entire soil cover, therefore the intensity of high quality soils consumption is much larger than can be expected from a structural pattern of soil quality.

3. Results and Discussion

Continuous urban fabrics cover 35 % of total area of the city and surroundings enclosed in Wroclaw LAU-2 region. Areas able to fulfill soil functions other than surface for construction consist with arable lands, semi-naturally covered lands, grasslands and forests – their share in total area is 22, 14.5, 11 and 7.7 %, respectively, which together exceeds 55% of total area (Table 1).

Table 1. Summary of land use changes in Wroclaw between 1991 and 2006

Land use class	area in 2006		area in 1991		difference	
	[ha]	% of total	[ha]	% of total	[ha]	%
continuous residential areas	5697.6	19.8	5322.2	18.5	375.4	7.1
commercial and industrial areas	2093.9	7.3	1946.3	6.8	147.6	7.6
green urban areas	697.7	2.4	697.7	2.4	0.0	0.0
airports	237.8	0.8	237.8	0.8	0.0	0.0
sports and leisure facilities	228.0	0.8	228.0	0.8	0.0	0.0
dump/mineral extraction sites	34.4	0.1	34.4	0.1	0.0	0.0
arable land	6406.4	22.3	6619.4	23.1	-212.9	-3.2
grasslands	3145.0	11.0	3242.4	11.3	-97.4	-3.0
forest	2207.4	7.7	2207.4	7.7	0.0	0.0
seminatural	4163.0	14.5	4387.3	15.3	-224.3	-5.1
discontinuos residential areas	1777.7	6.2	1781.8	6.2	-4.1	-0.2
water bodies	767.1	2.7	751.4	2.6	15.7	2.1
transport facilities	1248.6	4.3	1248.6	4.3	0.0	0.0
total area	28704.8	x	28704.8	x	x	x

The area of continuous sealed surfaces increased by over 500 hectares within the period of interest. Most of this change can be referred to residential areas. Discontinuous residential zones did not expand recently - they cover approximately 6 % of total area. Such areas with dispersed pattern of buildings may perform soil functions in certain extend due to substantial share of uncovered surfaces and undisturbed soil profiles.

The distribution of new sealed surfaces over soil quality classes are presented on Figure 4. The statistics of soil consumption for urbanization indicate preferential use of high quality soils in Wroclaw (TI>1.3, 3.6% of high quality soils consumed). Share of the weakest soils in newly sealed area was much smaller than their share in total resources despite that their supply is substantial (Table 2).

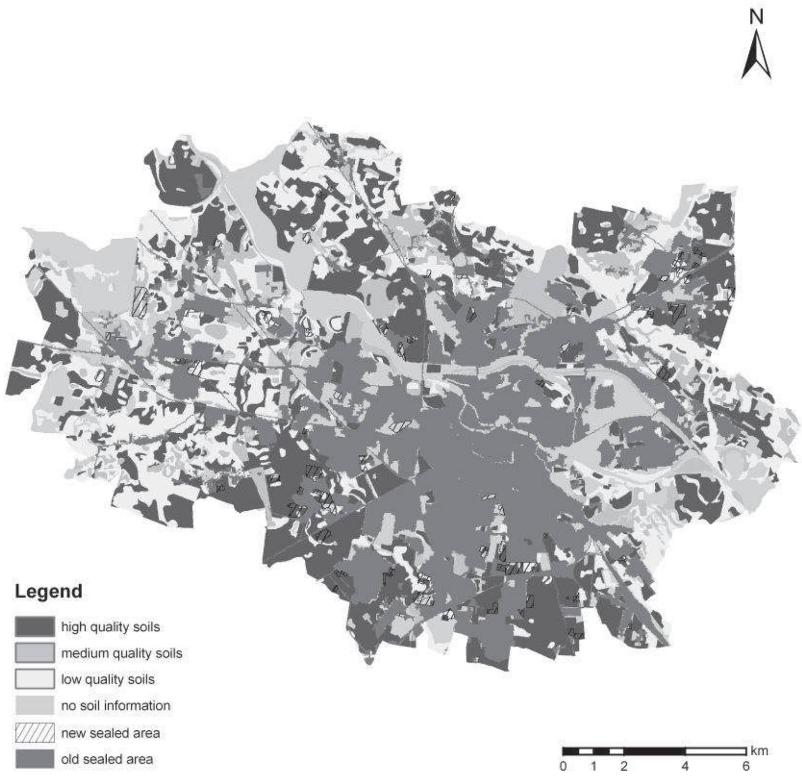

Figure 4. Urban sprawl in Wroclaw between 1991 and 2006 on soil quality map

The land use change data provided here may be somewhat different from the official statistics that use different methodologies, however the assessed level of the change of agricultural lands into sealed area was sufficiently precise as confirmed by the city administration. Our study utilized satellite images for detection of land use changes – such a method is burdened with a dose of uncertainty. However the advantage of the applied approach is that it enables analysis of spatial trends of land use change and their linkage to soil quality information.

Table 2. Indexes for transition of soils of different quality into sealed area for Wroclaw

soil quality class	Area of soil class (ha)	Share of soil class in total area [%]	Area converted (ha)	Percent converted [% of soil class area]	transition index (TI)
high quality	7377	48.6	266	3.6	1.33
medium quality	2259	14.9	42	1.8	0.68
low quality	5547	36.5	105	1.9	0.69

The expansion of artificial surfaces took place equally on arable and semi-natural lands. New artificial surfaces mostly comprised with residential fabrics to fulfill demand for inadequate housing provision. The analysis fills the information gap on the quality of soils lost in urbanization process and, thus, efficiency of soil protection approaches.

It is evident in the light of this study that the best soils were not efficiently protected in Wroclaw. It is assumed that the regulations present in Slovakia help to protect the most valuable soils. The soils classified as high quality had been covered by the fee payment. Transformation of these agricultural lands into other purposes was loaded with obligatory payment with a range of payment from approx. 6 to 10 EUR per square meter, depending on the soil class. Additionally, each transformation of agricultural soils of best classes into non-agricultural use must have been approved by the Ministry of Agriculture if the area exceeded 0.5 ha. The collected fees fully supply the Fund of Land Protection that is spent for land protection, recultivation and improving soil quality (e.g. liming). This regulation had covered all soils until 2008, after this date the urban soils have been excluded from this instrument. The described practice did not ensure the efficient protection of most valuable soils in Wroclaw.

4. Conclusions

Combination of satellite image based land use change maps and soil maps provided valuable information on trends in soil cover management under urbanization pressure. The assessment performed for Wroclaw revealed negative trend of preferential use of the most valuable soils.

Most of new urban sprawl took place on arable and semi-natural lands. Despite the fee payment instrument, existing within the period under analysis, the best performing soils were not sufficiently protected. It can be partly explained by the spatial distribution of the most valuable soils and still limited establishment of the soil issues in the law regulating land management.

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