Consequences of limited soil protection in cities of Central Europe analyzed through GIS methods and participatory impact assessment – URBAN SMS project

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Abstract. Various methods were utilized for assessment of soil consumption patterns and trends in the cities of Central Europe within Urban Soil Management Strategy (URBAN-SMS) project. They included ex-post assessment of soil loss based on land use change data, modeling of future soil loss and participatory impact assessment. The major data inputs for ex-post and ex-ante assessments were satellite image based land use maps and soil maps. The participatory impact assessment involved series of meetings with stakeholders and collecting their opinions in a semi-quantitative form. Existing soil management systems in these cities did not efficiently protect the best soils until 2006. Continuation of current management would lead to further non-sustainable trends. The analysis revealed that there is no strong conflict between soil protection goals and demand for land related to economic development of the cities.

Keywords: land use, modeling, participatory impact assessment, soil, sealing

1. Introduction

During the last decade more emphasis was given to functions of landscapes and their sustainability as a response to a need to minimize the depletion of agricultural land resources and to reduce environmental and social impacts caused by land use changes. The changes are not limited to land cover only, but potentially lead to disturbance of landscape functions. The soil framework strategy presented by the European Commission (COM 231, 2006) identifies number of threats to maintaining soil functions in Europe: erosion, decline of organic matter, local and diffuse

In: M. Salampasis, A. Matopoulos (eds.): Proceedings of the International Conference on Information and Communication Technologies
for Sustainable Agri-production and Environment (HAICTA 2011), Skiathos, 8-11 September, 2011.

contamination, sealing, compaction, decline in biodiversity, salinisation, floods and landslides. Sealing is one of main threats itself, additionally urbanization of agricultural land may accelerate the other degradation processes (Stuczynski, 2007).

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. Soil plays a particular role in supporting the environmental stability based on its retention, buffering or provision of biodiversity potential. Soil quality is also important to food safety and broadly understood population health.

There are different approaches for impact assessment of spatial development or soil protection policies. Analytical approaches utilizing spatial information systems are represented by ex-post or ex-ante assessments of soil loss during urbanization process. Another approach involves participation of local stakeholders and, thus, might be called 'participatory impact assessment'. The major part of this approach is collecting opinions of stakeholders on possible urbanization consequences. The advantage of this method is that it involves individuals familiar with local circumstances and needs, and allows to collect data also on social and economic issues - which data is usually scarce and not present in spatial format.

The objective of the paper is to present various approaches for assessment of urbanization pressure consequences for soil resources within cities of Central Europe. The detailed goals were:

- to conduct an ex-post analysis of land use change, responding to different soil protection regulations in several Central Europe cities
- to forecast urbanization sprawl in the pilot cities up to year 2030 for the baseline scenario that assumes that there are no limitations for soil consumption as related to soil quality
- to gather opinions of stakeholders on key sustainability issues in cities of Central Europe and potential impacts of soil protection scenarios in a semi-quantitative form

2. Materials and Methods

2.1. Data

One of major constraints in spatial analysis of land use change is the quality of mapping and uncertainties of cartographic information related to different sources, scales and methodologies of land use map preparation. Resolution of official European land use database Corine Land Cover (CLC) is inadequate for detailed analysis of transition occurring in urban and suburban zones (EAA, 2005). Thus, satellite images gathered from one source were employed for analysis of land use conversion trends in the test areas in order to ensure consistency of land cover data and allow comparability of results between cities. These were 10-meter resolution SPOT satellite images. The B&W SPOT image is monospectral, color photo is a combination of 4 bands of different wavelengths.

The images represented two periods to enable the study of land use change trends within reasonable timeframe. The black and white photos were captured in 1990-1992 and color photos were taken in 2006-2007 period. One or two year difference between cities was justified by the necessity to avoid low quality images, e.g. due to excessive cloudiness.

Due to diverse soil quality assessment systems, present in different Central European countries, and content of the soil maps the polygons on each map were grouped into 3 classes. They represented high, medium and low quality soils (either from perspective of production function, ecosystem function, buffering, retention etc.). For example, the soil map of Bratislava contains soil quality classes according to Slovakian valorization system in the 1 to 9 scale. Classes 1-4 were taken to the high quality soils group, 5-6 to medium quality while classes 7-9 were considered as low quality soils.

2.2. Analytical Approaches

Ex-post soil consumption assessment. The framework of the analysis of loss of high quality soils in test areas involved development of land use change maps based on consistent satellite image data, analysis of land use change trends within 15 years period and subsequent assessment of on what soils the urbanization took place. The analysis was performed for Bratislava, Prague, Vienna, Stuttgart, Milan, Salzburg and Wroclaw. Land use maps of 10-meter resolution were produced for two periods representing years 1990-1992 and 2006-2007 through classification of the satellite images in Definiens Professional software. Land use maps contained 13 different land use classes. Subsequently, the land use change information was superimposed on maps of soil quality to gather information on soil quality cover by the 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 valuable soils loss through urban sprawl, a transition index (TI) was used. It reflects the intensity of land use flows in the context of soil quality [Stuczynski, 2007]. The contribution of e.g. soils of high productivity or high water retention potential to the total soil cover may vary greatly between regions – therefore the size (measured in hectares) of change is not a good indicator if these soils are preferentially taken by urbanization. Preferential flows occur when a certain soil type (characteristics) represents a larger share in the changed land as compared to the share of this type in the general soil cover.

The TI is the ratio between the share of a given soil type (class) within the changed area and the share of this class in the total soil cover.

It must be noted that for calculation of share of different soil quality classes in whole area only soils that were not sealed in 1990-1992 were taken into account. In most cities soil maps did not cover forest areas, except Stuttgart and Prague, for these two cities forest areas were excluded from the calculation since they are generally protected against urbanization.

Interpreting the transition index is straightforward – for example, if the percentage share of high quality soils within area changed into built-up areas is considerably smaller than 1 (e.g 0.5) it means that these soils are protected from expansion of artificial surfaces.

Ex-ante assessment of future soil loss. Modeling is becoming an important tool in context of conflicts between urbanization and landscape or soil protection, since urbanization driven degradation processes are often irreversible. Even if the prediction power of models is sometime limited, they can provide valuable insights into the development of trends caused by different soil protection regulations or simply spatial distribution of valuable soils. The idea of using models lies in their ability to detect possible conflicts which may arise as a result of existing or implementing given new policies affecting land use (Hilferink & Rietveld, 1999; Westhoek et al., 2006).

In the analysis we used the Cellular Automata-based Metronamica model. The software was developed and provided by the Research Institute from Knowledge Systems (RIKS) from Maastricht, The Netherlands (RIKS B.V., 2005). The software utilizes cellular automata model to spatially distribute areas of particular land use classes. Cellular automata (CA) is a discrete model which uses regular grid of cells, each classified within finite number of states. In case of Metronamica land use change modeling, these states refer to land use classes.

The land use maps and the soil maps, described in the previous section were converted to raster data with grid resolution of 50 meters. It has been observed that new residential areas were rather clustered and did not exhibit elements smaller that 50 meters.

In the modeling process the neighborhood of a cell (surrounding cells) influences the transition of this cell into other class in the next time step. The cells located further away have a smaller effect than cells closer to the centre cell. The transition rules are the core of the CA and determine if, and how, the state of each cell in the next time step changes.

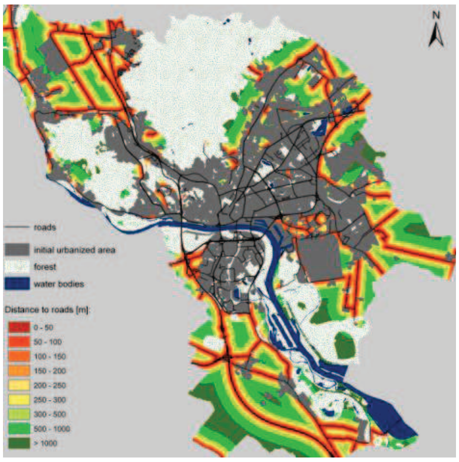
The neighborhood effect in this analysis is defined as: the attraction or repulsion effect of surrounding cells which eventually causes a change in cell status (type of land use) of the centre cell. For each land use function, a set of rules determines the degree to which it is attracted to, or repelled by, the other functions present in the neighborhood.

In our simulation, based on the neighborhood land use interaction and, so called, land suitability, the model calculates the value of transition potential (Pk) for each cell and land use function and for every simulation time step. All cells are ranked according to their transition potential, and cell transitions begin with the highest ranked cell and the transition process proceeds downward.

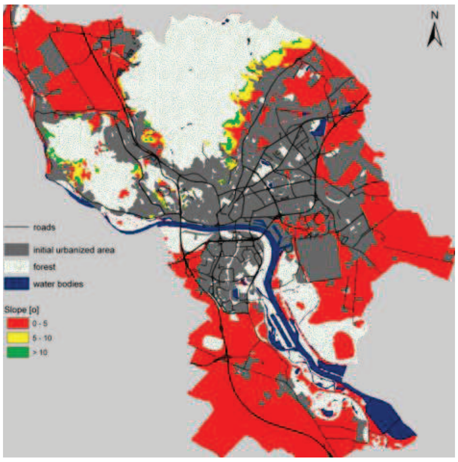
Land suitability is used here to describe the degree to which a cell is able to support a particular land use function. For transition into residential areas the Land Suitability (LS) includes four factors: terrain suitability S (slope), road accessibility S (distance to road), urban potential S (density of urbanized cells) and soil suitability S (soil). It is also assumed that these factors work independently so that the final land suitability (LS) is a product of them (1):

$$LS = S\,(slope) \cdot S\,(dist.\ To\ road) \cdot S\,(urban\ potential) \cdot S\,(soil) \qquad (1)$$

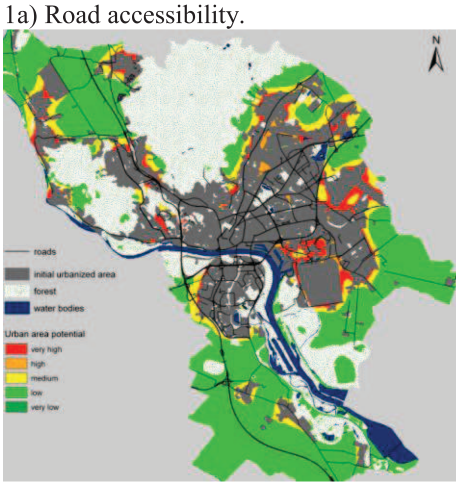
Values for first three factors were derived from share of new urbanized cells that appeared in the selected groups (percent slope or distance to road or density of residential area in a neighborhood of cell) between 1990/92 and 2006/2007.
All three partial suitability layers were normalized to reach values within range from 0 to 100 (0 means that a given cell is not useful for residential area, 100 means that there are no limitations to allocate urban function in this cell). Since in the baseline scenario, described in this paper, no limitation in soil take up was assumed, the soil suitability values for all three soil quality classes had the same value, equal 100.
The exemplary input data used for preparing maps of suitability components of the Land Suitability for Bratislava are presented on Figure 1.



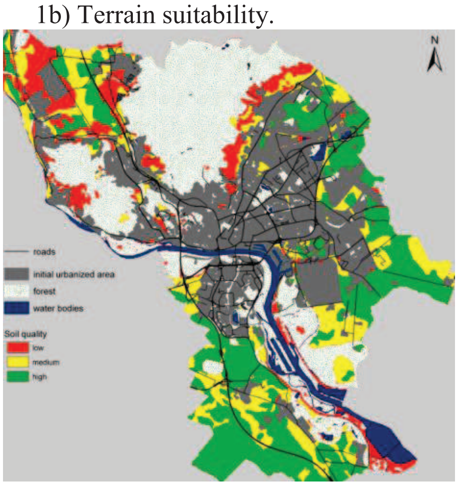
1a) Road accessibility.



1b) Terrain suitability.



1c) Urban potential suitability.



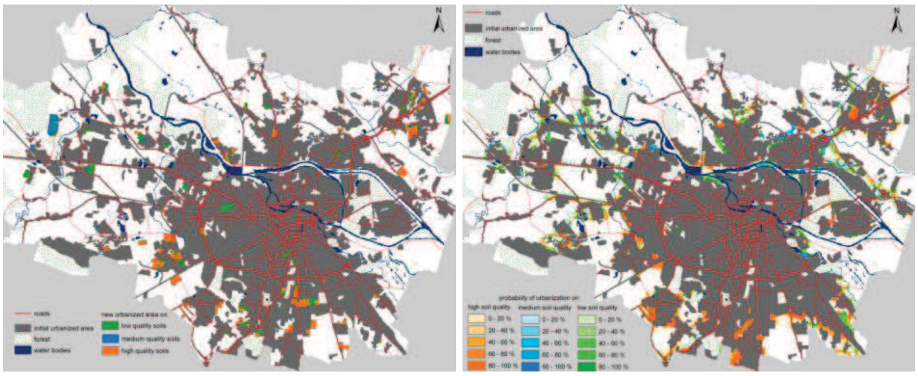
1d) Soil suitability.

Figure 1. Spatial input data for land suitability components for Bratislava area

Similarly as the ex-post analysis, the ex-ante assessment was performed for Bratislava, Prague, Vienna, Stuttgart, Milan, Salzburg and Wroclaw.

For the modeling purposes the original 13-class classification was reclassified to 4 classes representing 4 groups of urban land utilization:
0) agricultural and semi-natural
1) residential continuous and discontinuous, commercial and industrial, dump and mineral extraction sites, airports, transport facilities, sport and leisure facilities
2) forests, green recreation areas
3) water bodies.
In the simulation process it was assumed that urbanization may take place only on agricultural and semi-natural areas (class 0), thus this group of land uses served as land pool available for the potential sealing. Generally use of forest areas is restricted in all cities, thus this class was excluded from allocation of new urban fabrics. Class 2 (forests and green recreation areas) and class 3 (water bodies) remained unchanged in the modeling – their areas did not increase nor were not reduced.

The maps were generated by Monte Carlo method (100 runs) to display probabilities for transformation of a given cell of agricultural or semi-natural area into urban function and were compared to the historical changes (Figure 2). The forecasted sealing sprawl was superimposed on the soil quality information in order to provide information on potential future loss of soil resources. Thus, the TIs were calculated also for the predicted future soil losses.



2a) historical changes 2b) forecasted no protection scenario

Figure 2. Historical (1990/92-2006/07) and forecasted soil sealing in Wroclaw. The forecast is expressed as probability (intensive color – the highest) of sealing of a given soil class (orange –high, blue – medium, green – low quality)

Participatory impact assessment. The applied approach was a modification of the novel methodology used in SENSOR project that was proposed by Morris et al. (2011). It is a participatory impact assessment method that involves work with a group of stakeholders representative for the area of interest. The procedure involved series of workshops during which the detailed set of questions led the stakeholders through steps of impact assessment in order to gather their opinions in a semi-quantitative form. Consistent methodology was applied to each pilot study area in order to explore locally defined sustainability issues, scenario impacts and sustainability limits, all in a form enabling comparison between cities. The workshops was organized for the following pilot cities: Celje, Vienna, Milan, Prague, Wroclaw, Bratislava.

The assessed soil functions were grouped into 3 sustainability pillars: social, economic and environmental – each pillar is represented by 3 functions. The group of social functions was represented by cultural, recreation and health functions. Cultural function of soil can be understood e.g. as resource of archeological information useful for capturing natural and human history of the site. Recreation function refers to soil ability to provide sites of natural character for spending leisure time. This is an important aspect of mental condition of the human population. Health function of soil has a direct link to soil quality – soil contamination with inorganic (e.g. cadmium or lead) or organic contaminants (e.g. Polycyclic Aromatic Hydrocarbons) may affect human health through number of pathways such as food contamination, soil inhalation, direst ingestion of soil dust or secondary ground, surface or drinking water contamination.

In traditional agricultural understanding soil function is considered as production of food and feed. This serves as one of economic functions. The two other are related to role of soil as a ground for industrial or residential construction and transport infrastructure.

Nowadays increasing attention is given to environmental functions of soils. In our analysis they were represented by habitat (biodiversity), buffering and retention functions. Habitat function is related to the role of soil in functioning of non-agricultural ecosystems and ensuring biodiversity of landscape. Buffering function of soil controls migration of contaminants in the environment. Sorption of organic contaminants or metals in soil protects against the contaminants transfer to biotic and abiotic components of ecosystem. Retention function is responsible for holding water in a soil profile and limiting risk of flood after heavy or long-lasting rains. Movement of contaminants and nutrients in profile of soil with high water holding capacity is slower since such soil reaches the full saturation much later.

The functions were ranked by the participants in scale from 9 to 1 with the assumption that each score may appear only once. Score 9 meant the most important soil function for the local conditions. The following functions were scored: cultural heritage (SOC-1), recreation (SOC-2), health (SOC-3), land based production (agricultural) (ECO-1), transport infrastructure (ECO-2), housing and workplace provision (ECO-3), biodiversity (ENV-1), retention (ENV-2), buffering and filtering (ENV-3).

Three scenarios representing different soil protection approaches were proposed to be assessed regarding their impacts on the soil functions in long-term perspective. They basically reflected the following criteria:

<u>Scenario 1 (the baseline scenario)</u>

It assumed that nothing would change in regulations concerning soil protection. Soil protection efficiency remains at the present level.

<u>Scenario 2 (moderate protection)</u>

City planners have to take into account the quality of soils and constructions can be placed on low and medium quality soils mainly.

<u>Scenario 3 (strong protection)</u>

Construction is placed on brownfields and low quality soils; if more area is needed construction can be placed on medium but more open space needs to be planned in these zones.

In the subsequent part of the meeting the potential impact of these scenarios on the soil functions was assessed. Each expert individually scored the potential impacts of a given policy scenario on the soil function within the range: -3 to 3:
-3 (strongly negative impact), -2 (moderately negative impact), -1 (slightly negative impact), 0 (no effect), 1 (slightly positive impact), 2 (moderately positive impact), 3 (strongly positive impact).

The last part of the meeting was aimed to discuss and set sustainability limits for each soil function in the context of the particular city. The experts were asked to consider what impact on a given function (expressed by the indicator) within urbanization process, within range –3 to 3, can be accepted.

3. Results and Discussion

3.1. Trends of Soil Loss – Ex-post Assessment

It is essential to understand what is the rate and pattern of changes in land use and how soil sealing affects the overall 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 current soil protection measures. Soils differ in properties and, thus, ability to fulfill such functions as retention, biodiversity, filtering, crop productivity. Land use change size and pattern usually reflects a combination of the geographic location, a specific setting of socioeconomic, historical and environmental conditions and national or regional land/soil protection policies. Therefore it is not practical to analyze these changes for the group of cities as a whole, but instead analyzing them separately since the test areas represent different mechanisms driving land conversion processes. It is well known that the size of conversion of agricultural land into artificial surfaces such as into urban and industrial/commercial units is mainly driven by population growth (both through natural growth and migrations) as well as GDP whereas the spatial sprawl of urban fabrics is partly an independent process and partly is steered by spatial planning.

The area sealed within 15 y period in the test areas ranged from 160 to 780 ha. The data provided here may be somewhat different from the official statistics that use different methodologies. 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.

The expansion of artificial surfaces took place mostly on arable lands, except Wroclaw and Stuttgart where semi-natural areas were also sealed substantially. New artificial surfaces mostly comprised with residential fabrics, however in some cities (Bratislava and Vienna) development of industrial and commercial constructions was predominant.

It is evident in the light of this study that the best soils are efficiently protected in Bratislava. The share of best soils in newly urbanized areas is in Bratislava 5 times smaller than their share in total area – TI=0.2 for the high quality soils. It is assumed that the regulations present in Slovakia help to protect the most valuable soils. The soils classified as high quality in our assessment are covered by a fee payment system (1-4 classes from total 9). Transformation of these agricultural lands into other purposes is loaded with obligatory payment with a range of payment from 6 to 15 EUR per square meter. The similar system had existed in Poland until 2008. However this practice did not ensure the efficient protection of most valuable soils in Wroclaw. In Stuttgart and Milan the consumption of high quality soils was rather proportional to their share in the total soil pool. The assessments performed for Wroclaw, Prague, Vienna and Salzburg revealed negative trends of preferential use of the most valuable soils. It must be noted that the analysis of soil protection efficiency refers to the period between early nineties to 2006/2007, thus it assesses the regulations existing within this period. It should not be referred to the soil management systems introduced recently.

The similar analytical approach as presented in this report can be used for testing how urban growth alters degradation processes (e.g. erosion, contamination) and affects soil function performance (organic matter accumulation, retention potential, buffering capacity) if such spatial information layers are employed in the assessment.

A comparison of a sealing rate within last 15 years and availability of low and medium quality soils indicates that there is no strong conflict between soil protection goals and development needs of the cities (Table 1). Such competition may exist locally but, considering this in context of overall city area, the pool of available low and medium quality soils is, for most cities, much greater than land demand for the city development (industry, commerce, transport infrastructure, sport facilities, etc.). This demand is measured by the rate of land transformation into artificial surfaces within last 15 years.

Table 1. Comparison of soil availability and land demand in the test areas.

Test area	Low quality soils[1]	Low and medium quality soils[2]	Land demand[3]
Milan	160	3103	364
Bratislava	3033	8941	391
Wroclaw	5547	7806	412
Stuttgart	706	1693	138
Prague	6863	18825	718
Salzburg	791	5601	82
Vienna	418	1850	213

[1] soils belonging to low quality agricultural lands (arable and grasslands) within areas covered by the soil maps

[2]soils belonging to low and medium quality agricultural lands (arable and grasslands) within area covered by the soil maps

[3]rate of artificial surface increase within 15 years in the area covered by the soil maps

3.2. Forecast of Soil Consumption up to 2030

Table 2 summarizes the forecasted Transition Indexes for high, medium and low quality soils in the test cities. Information provided by these statistics informs on potential allocation of artificial surfaces when no particular protection of valuable soils is present. In such case urban fabrics appear in most attractive locations in terms of distance to transport network and other types of land use and slope. The scenario with no particular protection instruments would result in continuation of non-sustainable soil management in the cities.

Table 2. Transition Indexes for soil consumption in cities of Central Europe forecasted for 'no protection scenario'

soil quality class	Wroclaw	Prague	Bratislava	Milan	Vienna	Stuttgart	Salzburg
high	0.86	0.86	0.63	0.59	0.65	1.04	1.25
medium	0.75	1.03	1.74	1.04	1.34	0.64	0.82
low	1.19	0.97	0.75	3.47	0.72	0.87	1.70

The transition indexes for simulated spatial sealing are compared to the similar indexes calculated for historical data on urbanization in each city (Figure 3). The TI's for high quality soils are in the 'no protection scenario' somewhat lower than in the past period, except Bratislava and Stuttgart. The most likely reason is drainage of stock of high quality soils in areas most attractive for built up. However the TI's would still remain at level near 1, which number must be treated as indicative of non-sustainable soil management.

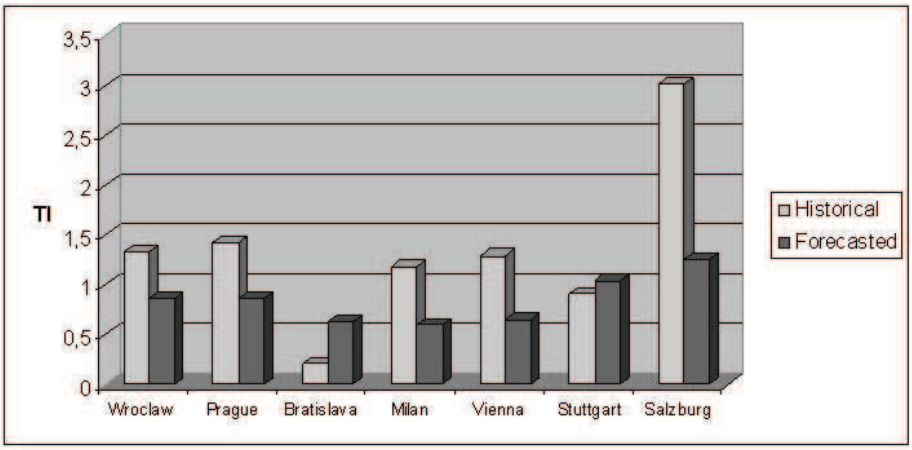


Figure 3. Comparison of the Transition Indexes (TI) for historical and forecasted sealing of high quality soils

3.3. Stakeholder Inclusive Impact Assessment of Soil Protection Scenarios

The approach of the impact assessment presented here involves participation of local stakeholders and is based on collecting their opinions on possible urbanization consequences. In general two economic soil functions ‘Housing and workplace provision’ and ‘Transport infrastructure’ were set as most important by the stakeholders. These circumstances make soil protection activities even more important. All environmental soil functions were classified as important to protect in all cities. The baseline scenario was assessed as favorable to economic functions ‘Housing and workplace provision’ and ‘Transport infrastructure’ whereas all environmental functions were deemed as threatened. Medium soil protection (no sealing on high quality soils) would basically sustain the soil environmental functions at the current level. The very important observation is that certain strengthening of soil protection (medium soil protection) would not restrict infrastructure and housing/industry construction below the limit acceptable by the local stakeholders (Figure 4). Exclusion of both medium and high quality soils from sealing (strong protection scenario) would be, according to the stakeholders, unacceptable obstacle for development of housing and workplace sector. However, this extreme scenario would highly improve the environmental soil functions. There is a general demand for improvement of soil environmental functions, such as retention, biodiversity and buffering, in the pilot cities.

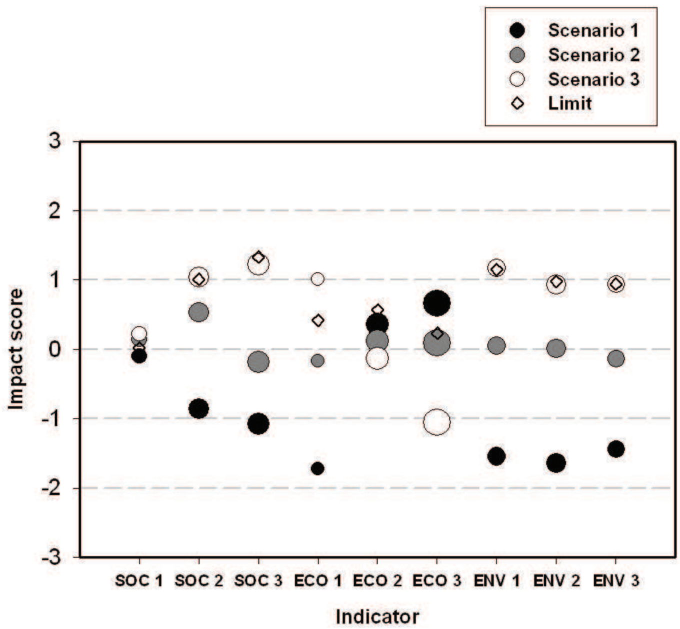


Figure 4. The average impact (across all cities) of soil protection scenarios on social, economic and environmental soil functions. Bubble size represents the average (across all cities) importance of the soil function. Rhombus represents the sustainability limit

4. Conclusions

Expansion of artificial surfaces in the test areas took place mostly on arable lands. High quality soils were efficiently protected in Bratislava which, at least partly, might be the effect of the fee payment system. The most valuable soils were preferentially taken for urbanization in Vienna, Wroclaw, Prague and Salzburg while in Stuttgart and Milan their consumption was proportional to their share in total area. Soil management systems in these cities did not efficiently protect the best soils until 2006. Interestingly, there is no strong conflict between soil protection goals and demand for land related to economic development of cities. The pool of available low and medium quality soils is much grater than the land demand for urbanization.

According to the cellular automata modeling, the baseline scenario, assuming no system for protection of most valuable soils, would result in continuation of non-sustainable soil transformation trends. If spatial distribution of valuable soils favors their sealing (located in attractive sites) more intervention policy is needed to protect best soils under moderate protection scenarios. There is a need for involving more detailed soil data in impact assessments of different soil protection scenarios and real soil management practices.

The participatory impact assessment revealed that in all the cities continuation of current soil protection regulations would lead to loss of all environmental soil functions. Economic functions were set as key issues for city development which makes awareness of soil role even more important. Better protection of soils is required to sustain or improve the quality of life in the cities. There is an expectation of stakeholders for improvement of environment status in the pilot cities. According to stakeholders – strengthening of soil protection (medium protection scenario) would not limit the economic development (land availability for new industrial and transport constructions)

Acknowledgments. The presented work was performed within Urban Soil Management Strategy project funded by the CENTRAL EUROPE programme

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