Vienna, Berlin, Warsaw. Comparison of spatial urban development patterns using remote sensing data and landscape metrics

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ABSTRACT

The most obvious effect of urbanization is the spatial expansion and morphological change of cities. There are many individual factors influencing the physical urban growth, however it can be observed, that almost every capital city in Europe increases spatially over time. In this study we aim to find similarities and differences in spatial growth dynamics, dimensions and patterns of selected European capital cities. Therefore we focus on three cities, namely Berlin (Germany), Vienna (Austria), and Warsaw (Poland). By means of multi-temporal Landsat satellite imagery (MSS, TM and ETM+ data) we classify the spatial urban footprint for four points in time namely 1975, 1990, 2000 and 2010, hence, over 35 years of urbanization can be monitored and quantified in a consistent way throughout the cities. Urban footprint classifications are derived using hierarchical, object-based image analysis. For the quantification of the particular urban patterns we apply various spatial metrics. The goal of the study is to compare spatial configurations of urban sprawl among the cities. Furthermore the study aims at answering the research question whether any significant differences in spatial development of the selected European cities exist.
We assume that spatial configurations may be varying in dependence of the political system and the change in Europe in 1989. Conducted study shows various spatial pattern as well as diverse magnitude of urban sprawl depending on geographical location and system which influenced particular each individual city.

INTRODUCTION

Urban sprawl is one of the leading forces that change our environment significantly (1). It turns neighbouring land use/land cover classes like forest or agricultural fields, into an irreversible urban environment. However, the urban sprawl definition is still fuzzy and many scientists contribute to understand and finally define the sprawl phenomenon in a more holistic manner (2, 3). Sprawl is related to low density built-up areas, or to leapfrog development (2, 4) on the one side and to low residential density or low accessibility and car dependency on the other side (2, 4). Among many available contributions (3, 5) remote sensing has proven its usefulness regarding to mapping urban sprawl. Multi-temporal satellite data make these non-invasive observations unprecedented to measure spatially growing cities either in semi-automatic (3) or fully automatic way (5, 6).

In this study we focus on the analysis of spatial urbanization processes on the European continent and put attention to three cities (Berlin – Germany, Warsaw – Poland and Vienna – Austria) that were located in various political systems before 1990 – a socialistic and a capitalistic system. Our hypothesis is that the mentioned political systems have had huge influence on the spatial urbanization patterns. Other studies reflect this assumption already (7, 8, 9) and we aim to enlarge the empirical knowledge about it. Based on multi-sensoral and multi-temporal Landsat (MSS, TM, ETM+) data we apply object based classification techniques to extract urbanized areas – the so called urban footprint. In addition, we apply landscape metrics and post-classification change

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detection to underline spatial differences of cities on various spatial levels. Generally, we aim to answer following question: Is there any significant difference in spatial pattern developments between socialistic and capitalistic cities?

STUDY AREA AND DATASETS

For the study purpose the three capital cities Berlin, Vienna and Warsaw were selected (see Table 1) in accordance to the geographical location and size of their populations. Capitals of Austria and Poland were selected as representatives who have been influenced by two different political systems – capitalism and socialism. The city of Berlin was chosen due to its specific character until 1990 – comprising of both systems.

Table 1: Descriptive information about cities area and population (http://www.citypopulation.de/index_d.html)

City name	Area (km2)	Population (mio)	City name	Area (km2)	Population (mio)
Vienna	414,65	1,731,236	Warsaw	517,24	1,711,324
Berlin	891,85	3,520,061			

The study is entirely based on Landsat data (MSS, TM, ETM+) provided by the USGS (United States Geological Survey). Landsat data are characterised by medium resolution of 30m and even only 59 m with Landsat MSS (Multi Spectral System). This causes problem of mixed pixels – as different land cover classes are part of one pixel, therefore problems with accurate classes' extraction occur. However, this geometric resolution has the general capability to delineate urbanized from non-urbanized land cover. This satellite family have been providing datasets since 1972, thus it is essential for long-time monitoring. With 185 km swath width the satellite is able to map large metropolitan areas.

METHODOLOGY

Land cover classification based on multi-sensoral and multi-temporal satellite data and change detection

The classification of Landsat data consist of: **(A)** pre-processing steps, **(B)** image segmentation and **(C)** classification to extract urban footprints (3, 10). Pre-processing **(A)** deals with selecting appropriate satellite images, where priority was given to cloud free images with accordance to four time steps: the years 1975, 1990, 2000 and 2010. In case of Landsat MSS due to only 4 spectral bands,Principal Component Analysis was used to enhance images visibility and reducing data redundancy. Secondly, a Tasseled Cap transformation was applied to create components which allow indicating places with impervious surfaces.

(B) (C) To retrieve urban footprint classifications from Landsat satellite data, an object based algorithm implemented in the eCognition software (10) has been used. The applied solution is based on a decision tree approach (3) with adjustable thresholds for pre-defined spectral information (11). This approach allows the user to recognize and classify urban areas in a semi-automatic way. The process of urban area extraction starts with segmentation. Segmentation deals with dividing satellite data into homogenous areas (polygons) based on spectral and spatial parameters. Thereafter the classification procedure has been employed to combine previously extracted segments with spectral information and indices such as the Normalized Difference Vegetation Index (NDVI) and the Soil Adjusted Vegetation Index (SAVI). Accuracy assessment was performed by distribution of 100 randomly distributed points within the particular urban class per city. The comparison of built-up and non-built up area was performed via a confusion matrix, where reference data (satellite images) have been compared with the classification results. Applying this method, characteristics such as: Overall accuracy, Producer's accuracy, User's accuracy as well as Kappa value were calculated

The spatial concept for the analysis of urban sprawl patterns

Analysis and comparison of cities can be conducted at different geometric levels – in general from the entire metropolitan are to the core city, to parts of the city or even individual objects. In our study we apply four different spatial entities: **LEVEL I** – the entire Area of Interest (AOI) (100 km by 100 km square with the fixed center point in particular downtown); **LEVEL II** – this level consists of an: **a)** inner area of the particular city (with a 13 km radius from the city center point). A 13 km radius was calculated using mean administrative area of all cities and equation for circle's area; **b)** a peripheral area (as a circle with the inner city area erased and a ring width of 12 km as a complementary value to 25 km width); **c)** the hinterland (representing the entire AOI with the inner as well as peripheral area erased); **d)** the administrative area of the particular city. *Figure 1* visualizes this spatial concept.

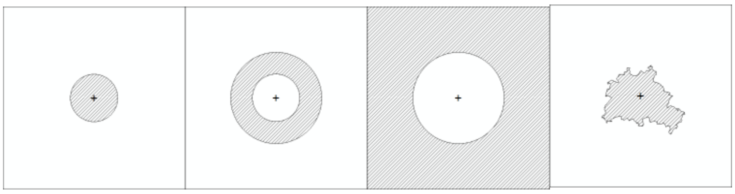

*Figure 1: Visual representation of spatial levels: (from left) core area **(a)**, periphery **(b)**, hinterland **(c)**, administrative unit **(d).** (Grey area – AOI)*

Spatial metrics for quantifying spatial patterns

The term "Landscape metrics" refers to algorithms that quantify specific spatial pattern characteristics of patches, classes of patches or entire landscape (12). Originated from landscape ecology research, spatial metrics have been recently introduced to measure spatial configurations of urban areas (13, 14). According to (12) we apply landscape metrics belonging to Area and Edge metrics as well as Aggregation metrics. The '*Class area'* (CA) measures the area of a specified class. With this metric we aim to define the dimension of the urbanized areas and absolute spatial expansion across cities. The metric '*Number of Patches'* (NP) equals the total amount of separate patches of one class. This metric involves the assumption that an increasing number of patches corresponds to a dispersion of the pattern. The metric '*Mean Patch Size'* (AREA_MN) is a measure that averages the size of all key components of fragmentation, while a progressive increase is a hint for redensification and coalescence (13).

EXPERIMENTAL RESULTS

The classification results for the three cities – Vienna, Berlin and Warsaw – show complex and differing urban patterns. The change detection is visualized in *Figure 2.* Overall accuracies of the classifications show promising results: Berlin – 83.5%, Vienna – 91.5%, Warsaw – 80.0%.

The results of the spatial analysis of pattern configuration are presented in detail below (*Figure 3, Figure 4*) based on the spatial hierarchy:

LEVEL I – the entire AOI

The spatial extent of the urbanized area has been growing for all three cites, however the magnitude of changes is the most immense in Warsaw.

LEVEL II:

a. core area – shows significant (2.5 times) growth in Warsaw's urban area since 1975. Vienna has doubled its size, where Berlin reveals the lowest growth in time – less than 50%. *'Number of Patches'* on this level is decreasing in each city in time, although the highest decrease can be noticed in Berlin between 1990 and 2000. The Warsaw's example shows less prominent changes and patches quantity is increasing, thus we claim that redensification processes of urbanized area have started earlier in Western European cities than in Eastern ones. Vienna was growing constantly since 1975 (almost 2 times

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comparing to its extent in 1975). *'Mean Patch Size'* underlines, that the core area of Berlin is the most concentrated, where on the other hand Warsaw is the most dispersed. *'Number of Patches'* proves this conclusion too.

b. peripherial area – Warsaw has grown almost 7 times since 1975 on this level. The most dramatically changes appeared since 1990.The Vienna city gained smoothly less area in time (6 times since 1975). In case of Berlin peripherial area growth is at minimum (1 time since 1975). Here the fact of the political system has had an influence to stark transformation from a 'socialistic city' to a 'capitalistic' one. Berlin's peripheries become denser as *'Number of Patches'* decreases and the *'Mean Patch Size'* increases in time. Concerning Vienna and Warsaw the areas of the periphery transform to more dense form too, however cities are continuously growing.
c. hinterland – on this level, the area of Berlin, Vienna and Warsaw increases constantly. Once again, the highest growth magnitude is visible in Warsaw and equals circa 20 times. In addition the further we are from the city center, the higher degree of patchiness is growing. Additionally, the 'Hinterland' level reveals that Vienna and Warsaw are growing continuously, as their *'Number of Patches'* as well as *'Mean Patch Size'* are growing in time. Berlin gain in area, nevertheless quantity of patches is lower comparing 1990 and 2010.
d. administrative area – the results obtained for this level reveals comparable trends in urban development as at 'core area' level, where Warsaw is the most rapidly expanding city, Vienna moderate and Berlin the slowest in the time period applied in the study.

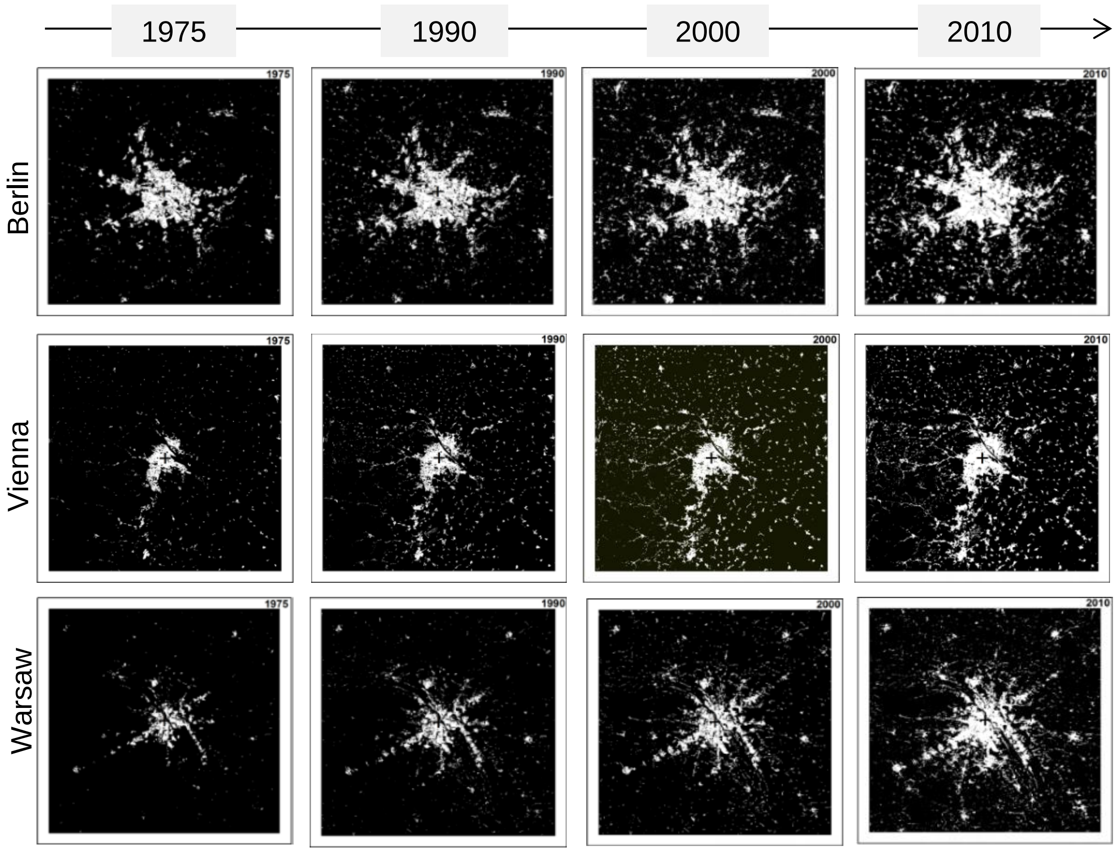

Figure 2: Cities change detection – comparison of extracted urban footprints (1975, 1990, 2000, 2010) for Berlin, Vienna and Warsaw. White colour signifies Built-Up area, where black colour stands for Non Built-up area.

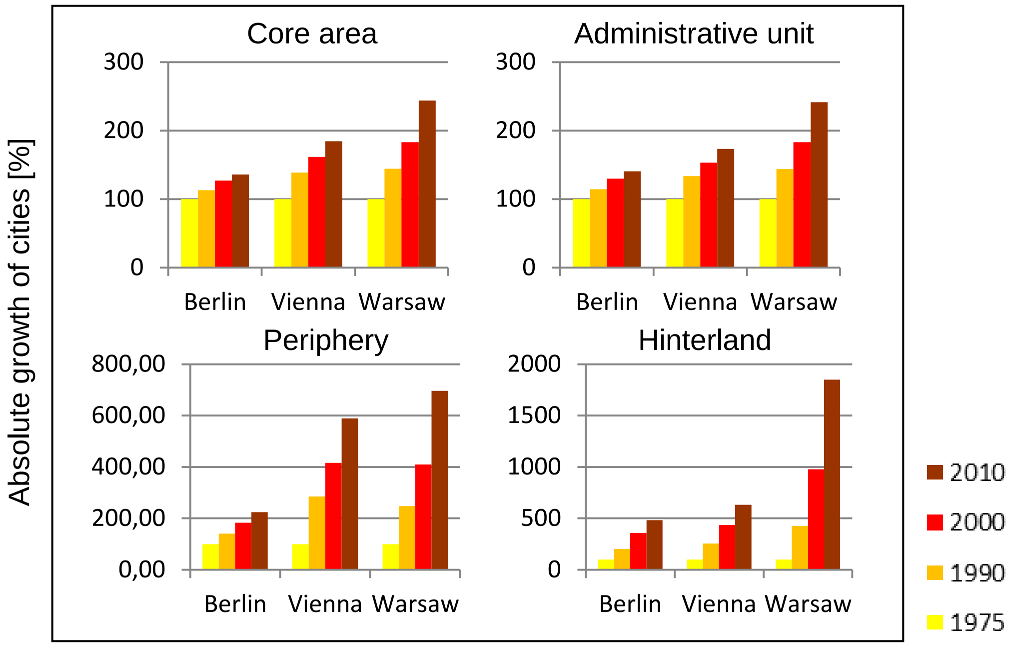

Figure 3: Absolute values of Class Area (CA) calculated for following spatial levels

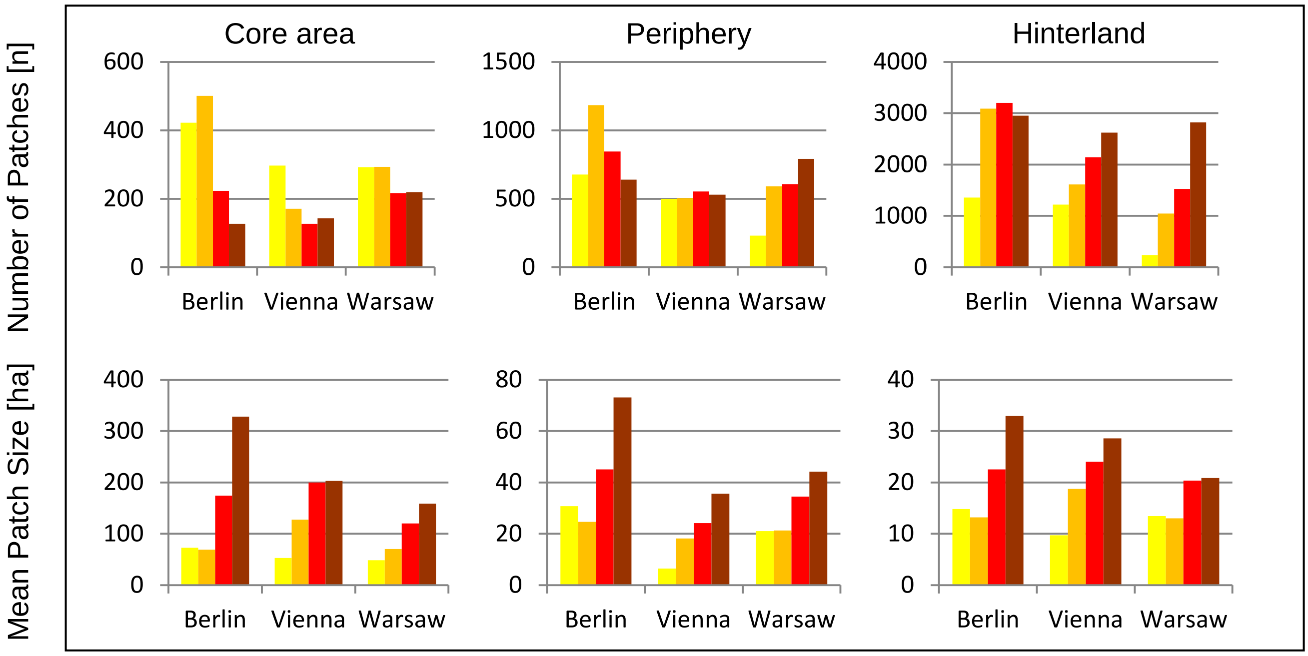

Figure 4: Visual comparison of landscape metrics calculated for spatially different levels.

CONCLUSIONS

The main findings of this study refer to the research questions stated in the introduction: Is there any significant difference between spatial pattern developments between socialistic and capitalistic cities? It becomes obvious that urban growth exploded after the collapse of the socialistic system in 1989 as it is shown in Warsaw's example. Since that moment the market as well as borders of former Socialistic countries started to be open for foreign investors. In our eyes this is the most prominent reason of acceleration in development of East European cities. Therefore, the magnitude of spatial growth is the most immense in Warsaw. On the other hand, Berlin reveals redensification processes as outcome of differing social lifestyle in Western countries which begun much earlier, than in case of Warsaw. The presented results exemplify doubtlessly diverse patterns of spatial urban development between selected European capitals.

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