Indicators for the spatial analysis of settlement and open land trends in urban areas - studies on base of five European cities over a 50-year period

Gotthard Meinel¹, Michael Winkler¹ and Carlo Lavalle²

Abstract

The expansion of urban settlements occurs in long-term periods which makes an immediate perception of this ecologically problematic process almost impossible. Analyses on the basis of administrative boundaries cannot reflect the development sufficiently differentiated. Based on GIS data sets for the cities of Bilbao, Bratislava, Lyon, Dresden and Palermo from the EC-project MOLAND the development of the urban settlements during the past 50 years is amplified by means of land use/land cover respectively transport system analyses and the jaggedness degree of the cities. In addition, the analyses were represented in a comparative manner and valued, urban settlements expansions were spatially presented, and the jaggedness degree was calculated and discussed. Furthermore, first conclusions about the common and the different features in the developments of the cities could be drawn.

1. Introduction

Urbanisation processes are amongst the most stable aspects of area development. The proportion of land used for construction purposes continues to expand even where there is negative population growth and economic stagnation. All known forecasts indicate that there will likewise be substantial growth in the amount of land used for settlement purposes in the years ahead. Although the main thrust of the growth in urbanisation is increasingly shifting to hitherto predominantly rural areas, further growth in settlement lands is also anticipated for urban nuclei and their immediate spheres of influence. Yet, already now these areas are regarded as being

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subject to considerable ecological strain due to their high degree of compression and, in some cases, extremely dense traffic networks.

Hitherto, it has only been possible to study urbanisation processes on the basis of official statistics. This data source offers low spatial resolution (local authority base) and, given that material and geographical references are subject to frequent change, only provides limited opportunities for multitemporal examination of land use trends. This information deficit has given rise to a research deficit - there have been few research studies to date devoted to the impact on settlement and open land structures of urbanisation and suburbanisation processes. Which governing factors lead to which changes in urban-region utilisation patterns must be deemed to be largely awaiting clarification. This holds particularly true beyond the frontiers of the Federal Republic of Germany. Comparative analyses on the development of urban land use structures are essentially non-existent.

Within the framework of the MURBANDY - Monitoring Urban Dynamics - search project, 21 European cities and 3 urbanisation regions have now for the first time mapped land use trends over the past 50 years using satellite and aerial imagery. The upshot is a highly accurate database to a scale of 1 : 25,000 that is underpinned by a finely nuanced use-type catalogue and survey slots in the mid-50s, late-60s, mid-80s and late-90s. Hence, it is possible for the first time to analyse land trends in the individual exemplar cities whilst also comparing these with those of other urban entities.

The talk draws on the findings of an in-depth analysis of the development of land use structures in the five city regions. A set of indicators is presented with the aid of which land development is to be portrayed in a spatially differentiated manner and evaluated in terms of its environmental impact. Amongst the points upon which light is shed are:

1. where and with what intensity land-take for settlement purposes occurs (disperse development, rounding-off, closing gaps etc.) and how spatial growth patterns alter over time
2. how the infrastructure system has changed and what correlations exist between settlement and infrastructure development
3. how urbanisation impacts on the quantitative availability and qualitative properties of open areas (size of open areas, level of severance).

The approach developed has potential for use as a means of refining indicator systems used in municipal and regional agenda processes, qualifying environmental observation practice and reporting mechanisms, and carrying out area-based, meta-project-level environmental impact assessments.
2. **Description of the Database**

The analyses were carried out for five of the 25 cities of the MOLAND project. Table 1 shows some important parameters.

<table>
<thead>
<tr>
<th></th>
<th>Bilbao</th>
<th>Bratislava</th>
<th>Dresden</th>
<th>Lyon</th>
<th>Palermo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative city area [km²]</td>
<td>41.3</td>
<td>96.3</td>
<td>328.6</td>
<td>47.9</td>
<td>152.2</td>
</tr>
<tr>
<td>Size of entire study area [km²]</td>
<td>180.0</td>
<td>248.4</td>
<td>405.6</td>
<td>311.6</td>
<td>223.1</td>
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<tr>
<td>Core zone [km²]</td>
<td>49.7</td>
<td>96.2</td>
<td>131.8</td>
<td>-</td>
<td>83.2</td>
</tr>
<tr>
<td>Buffer zone [km²]</td>
<td>130.3</td>
<td>152.2</td>
<td>273.8</td>
<td>-</td>
<td>139.9</td>
</tr>
<tr>
<td>Population [per 1000]</td>
<td>368</td>
<td>452</td>
<td>478</td>
<td>445</td>
<td>741</td>
</tr>
</tbody>
</table>

Table 1
Overview of the studied cities

Although the data was captured under the instructions of the Strategy and Systems for Space Applications Unit of the JRC (Ispra/Italy) according to a strictly determined land use classification key and digitising rules (minimum mapping units, generalisation rules, minimum width of linear infrastructure etc.), several acquisition and processing differences in the data had to be noticed (partly lacking generalisation, varying digitising density, problematic or missing definition of the core area; example Lyon - see Table 1). The control of the observance of the guidelines to obtain homogenous, and therefore comparable GIS data sets recorded by more than 20 parallel working European teams is an enormous challenge. Hence, making it almost impossible to fulfill all the aforesaid conditions, slight inhomogeneities have to be accepted.

3. **Development and comparison of the land use analyses**

For all of the five cities the respective used areas were calculated for each land use category at all four hierarchic levels and for each of the four time slots. To differentiate the developments in the core zone (city area) from those in the buffer zone (surrounding area) the calculations for each region were carried out separately (Figure 1, 2). All of the studied cities went through a similar development of the urban areas with a visibly decelerated increase in the core areas in the 90s, whereas there was a constant growing in the buffer zones (suburbanisation tendency). Essentially, agricultural and forest areas have retreated from the urban area expansion. Most apparent were the processes in Bratislava and Palermo. Whilst the increases of settlement areas in the core zones were relatively low – from the mid-50s until the late-90s about 250 % – the growths in the buffer zones were much more higher (Bratislava 400 %, Palermo 950 %).
Figure 1
Development of major land use classes in the core zone

Figure 2
Development of major land use classes in the buffer zone
4. Development and comparison of the transport infrastructure

The comparison of the transport infrastructure was accomplished by the aid of the computation of the total length (Figure 3) and the network density of the classes “Railways”, “Toll ways” and “Other roads”, resulting in an enormous development of the “Toll way” network in all of the studied cities except Dresden. The network of “Other roads” shows a huge increase both in the core and in the buffer areas. Contrary to that, the study of the “Railway” network yielded in a retrogression in the 1990s (in particular in Lyon and Palermo) after a more or less constant growth until the middle of the 1980s.

![Figure 3](image_url)

Development of transport lengths of the entire study area

5. Spatial description of development

Beside the area analyses the presentation, quantification and assessment of the spatial pattern of the urban development are of great importance for an ecological evaluation. Figure 4 shows the development of the urban settlements of Palermo. A very disperse developing of the settlements from 1963 till 1989 is obvious. Particularly the settlement pattern in the South West of the city draws the conclusion that
the development had not taken place on the basis of a regional planning concept. From the ecological viewpoint that disperse settlement pattern has to be appraised as markedly questionable. The fragmentation of the landscape affects the flora and fauna in a negative manner. Furthermore, the accessibleness of large leisure areas has declined. Yet, this extremely disperse development could be stopped in the 1990s (Figure 4).

Figure 4
Development of urban settlement in Palermo
6. Jaggedness degree

The jaggedness degree is a quantitative measurement to describe the structure of settlements. It reads:

\[
\text{Jaggedness degree} = \frac{\Sigma \text{Perimeters}}{2 \sqrt{\pi \Sigma \text{Areas}}}
\]

The formula is based on all polygons belonging to the classes 1.1 (Urban fabric) and 1.2.1 (Industrial, commercial, public and private units). A dense city has a smaller jaggedness degree to show than one with a disperse structure. The aim of a sustainable city planning is a compact structure, so as it is possible to avoid heavy traffic.

<table>
<thead>
<tr>
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<th>Lyon</th>
<th>Palermo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-50s</td>
<td>16.8</td>
<td>18.5</td>
<td>37.1</td>
<td>33.3</td>
<td>21.3</td>
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<tr>
<td>Late-60s</td>
<td>20.8</td>
<td>18.4</td>
<td>34.9</td>
<td>32.3</td>
<td>25.1</td>
</tr>
<tr>
<td>Mid-80s</td>
<td>20.9</td>
<td>17.4</td>
<td>31.9</td>
<td>28.1</td>
<td>29.8</td>
</tr>
<tr>
<td>Late-90s</td>
<td>21.3</td>
<td>16.9</td>
<td>32.0</td>
<td>25.0</td>
<td>30.5</td>
</tr>
</tbody>
</table>

Table 2
Jaggedness degree

For Bratislava, Lyon and Dresden the jaggedness degree has declined due to redevelopment and infill in the urban centre, e.g. constructing on abandoned land. Bilbao and particularly Palermo stand out because of a constant growth of the jaggedness degree, which is a quantitative proof for the extremely disperse structures in the buffer zones. Retracing these trends is possible by comparing the spatial pattern of the urban settlement development. Beside the jaggedness degree the compactness degree which is based on the gravitation theory is a quantitative measure describing the density of a city (Thinh, 2001). The Total urban-edge composition, the Green Edge Index and the Habitat Suitability Index (Lavalle, 2000) are other methods to describe the settlement pattern.

7. Summary and Outlook

Digital land use data sets on vector basis, compiled for a period of 50 years, made quantitative studies of artificial surfaces and open spaces of selected European cities possible for the first time. Beside land use and transport system analyses in a compact, comparative representation the cities were described by means of the jagged-
ness degree. A corresponding result for all of the investigated cities is a considerable increase of the artificial surfaces. Whereas the growth of the urban settlements in the core areas in the 1990s did not reach the dynamics of the period from the middle of the 50s till the middle of the 80s, the processes in the buffer zones have taken place without any interruptions, which is not considered as recommendable for the ecology.

Further comparisons of urban dynamics for the five of the cities are planned by means of calculations of the compactness degree, the determination of the average distance of new built settlements from the core area and the evaluation of new built settlements in conjunction with the core zone (Meinel, 2000).

Bibliography


Lavalle, C. (2000): European Common Indicators and GIS/Spatial Aspects, in: European Common Indicators Workshop, Seville, 5-6.10.00 (http://moland.sai.jrc.it/)


Thin, N. et al. (2001): Searching for sustainable urban land use structures using GIS and cluster analysis


Internet: http://moland.sai.jrc.it/