Application of a new GIS tool for urban sprawl in Europe

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Land, as a multifaceted and finite resource that sustains every aspect of our society, requires efficient use. Limiting overall land take and proper management of urban sprawl patterns are being recognised as increasingly urgent at the European level, and goals and options for EU contributions to a more sustainable management of land as a resource are currently being discussed. Thus, at the EU level, a number of milestones are proposed regarding land and soil that reflect Rio+20 global ambitions and related targets that are already supported by many EU policy instruments. Even though the great importance of the problem is now recognised, to date there is no regular monitoring of land consumption and urban sprawl in place at the European level. The ongoing research project entitled Urban Sprawl in Europe aims to measure urban sprawl in Europe and contribute to filling this gap. This article provides an overview of the main elements of the application of new urban sprawl measures at the European level, the strategy used for their implementation, as well as the first results.

1 European context

Over the past decades, the European Union has put in place a broad range of environmental legislation. As a result, air, water and soil pollution has been significantly reduced. However, many challenges persist, and these must be tackled together in a more structured and coordinated way. One of these is an efficient use of land as a multifaceted and finite resource that sustains every aspect of our society, from food to products, buildings and energy. As stated in the latest report on the State and Outlook of Europe’s Environment published by the European Environment Agency in 2015 (EEA 2015): “Across Europe and the world, accelerating rates of urbanisation, changing demographic and consumption patterns, technological changes, deepening market integration, and climate change place unprecedented demands on land. Yet the availability of land is finite. This imbalance is unsustainable.”

While limiting overall land take and proper management of urban sprawl patterns are already important policy objectives at national or sub-national levels worldwide, these are also gradually being recognised as increasingly urgent issues at the European level. Consequently, objectives and options for EU contributions to a more sustainable management of land as a resource are currently being assessed.

Thus, at the EU level, the 2020 road map for a resource-efficient Europe proposes a number of milestones regarding land and soil as a reflection of the Rio+20 global objective to achieve a land-degradation-neutral world by the year 2030. Furthermore, the EU targets as set out in the 7th Environment Action Programme also deal with sustainable cities and the Union’s natural capital aiming towards no net land take in Europe by 2050. These targets are also recognised and supported by many other EU policy instruments such as the EU Green Infrastructure strategy, the EU CAP reform 2014–2020, the EU Forest Strategy, and the European Commission’s procedures on “Land as a Resource” to be included in next year’s Commission Work Programme.

2 Project “Urban Sprawl in Europe project”

Although the great importance of the problem has been recognised, no regular monitoring of land consumption and urban sprawl in Europe is currently in place. The EU appears largely unaware of the real scale of its land consumption, its spatial distribution, patterns and temporal trends, as well as the environmental, social and economic impact. Thus, an ongoing research project entitled Urban Sprawl in Europe aims to measure urban sprawl in Europe and make contributions towards filling this gap. To date, the European study, supported by FOEN and EEA, has applied the method of urban sprawl measurement tested in Switzerland (Jaeger and Schwick 2014) to the European context for the years 2006, 2009 and 2012.

2.1 Method

Every meaningful method for measuring the degree of urban sprawl needs to be based on a clear definition of “urban sprawl”, separating causes and consequences of urban sprawl from the phenomenon of urban sprawl itself, as urban sprawl has differing causes and consequences in different regions and regulatory contexts.

Although the literature provides a variety of definitions of urban sprawl (e.g., Brueckner 2000; Ewing 1994/2008; Ewing et al. 2002), there is no general agreement about what defines urban sprawl, and most definitions are too vague to serve as a basis for measurement (Besse and Chiu 2003; Jaeger et al. 2010). As a result, many measures of urban sprawl suffer from a confusing variety of differ-
ing, and sometimes contradictory, interpretations of the term. Consequently, findings from different studies cannot usually be compared to each other and may be difficult to interpret consistently.

A systematic evaluation of existing definitions of urban sprawl shows that most definitions have several features in common (Jaeger et al. 2010). These include making reference to:
- expansion of urban areas
- scattering of settlements, i.e., how strongly clumped or dispersed patches of urban area and buildings are,
- low-density development, i.e., how houses are dispersed in the landscape (area-intensive growth).

**Urban Sprawl definition and dimensions**

Taking these common characteristics into account, the following definition is used in the Urban Sprawl in Europe project: “Urban sprawl is a phenomenon that can be visually perceived in the landscape (within a defined horizon of perception). A landscape suffers from urban sprawl if it is permeated by urban development or solitary buildings and when land uptake per inhabitant or job is high. The more area built over in a given landscape (amount of built-up area), and the more dispersed this build-up area in the landscape is (spatial configuration), and the higher the uptake of built-up area per inhabitant or job is (lower utilisation intensity in the built-up area), the higher the degree of urban sprawl.” (Jaeger and Schwick 2014, «sic»). See Figure 1 for more information.

The causes and consequences of urban sprawl are distinguished from the phenomenon of urban sprawl itself, and are therefore not part of this definition (Jaeger et al. 2010).

**Calculation formula**

To measure the degree of urban sprawl in the Urban Sprawl in Europe project, we used the method of weighted urban proliferation (WUP). WUP is the composite metric to quantify urban sprawl in any given reporting unit and has three components: the percentage of built-up area, the dispersion of the built-up areas, and land uptake per person (Fig. 2):
**Fig. 3. Examples of the three available Copernicus Land service products (from left to right):** CORINE Land Cover, HRL Imperviousness and Urban Atlas. Data can be seen on the Copernicus Land portal http://land.copernicus.eu/

2.2 Data

The main challenge to applying the urban sprawl methodology successfully used in the Swiss studies to the European context was dealing with the (non-) availability of harmonised Europe-wide datasets that describe particular components of the WUP of urban sprawl. Spatial datasets that are suitable for a European analysis must:

- provide pan-European coverage
- be homogeneous and comparable in space and time
- be assured of frequent updating based on regular dataflows.

**Copernicus Land data for built-up patterns**

Fortunately, spatial data describing built-up area amount and dispersion can be based on EO-based European data from the Copernicus Land programme. Three available datasets are relevant to urban sprawl: CORINE Land Cover, HRL Imperviousness and Urban Atlas. Based on initial testing, the HRL Imperviousness dataset was selected as reference data based on its impressive spatial coverage (EEA38), high spatial resolution (20 × 20 m pixel), as well as its rich temporal coverage for 2006, 2009 and 2012 reference years.

**HRL – the Pan-European High Resolution Layers from the Copernicus Land Service** are produced for five themes: Level of soil sealing (Degree of Imperviousness), Forest, Permanent grassland, Wetlands, and Water bodies. All HRLs cover 39 countries in Europe and are available in the original 20 × 20 m spatial resolution (from satellite images) and as a validated 100 × 100 m product (most recent data are from 2012). The HRL Imperviousness provides more detailed data (20 × 20 m = 0.04 ha) about sealed surfaces than the CORINE Land Cover (25 ha resolution for each point in time and 5 ha for changes) and the Urban Atlas (0.25 ha resolution). Based on the results from a comparative study using various levels of imperviousness, a threshold of 30% was chosen to differentiate between urban and non-urban pixels (Orlitová et al. 2012).

**Eurostat data for population and employment**

Population and employment data at the European level were provided by EUROSTAT (ESTAT). Regional demographic statistics at the NUTS0/NUTS2 level are available at the Eurostat data portal with rich spatial and temporal coverage. The database includes 35 countries (EU28, EU candidate – ME, MK, TR, and EFTA countries – IS, L I, NO, CH). Statistics are based on census data released yearly.

In addition, population data are also available in a 1 km-grid dataset, which provides a much finer spatial resolution (http://ec.europa.eu/eurostat/web/gisco/geostat-project). Data came from the ESTAT GEOFAT project with spatial coverage that included EEA38 countries except for Balkan countries and Turkey, and temporal coverage that includes 2006 – GEOSTAT2006 (1A) and 2011 – GEOSTAT2011 (1B). We determined the values for 2009 by interpolating between the values of 2006 and 2011.

Employment (jobs) statistics were prepared from the EU LFS – Labour Force Survey (EUROSTAT) with a
spatial coverage of EEA33 = 28 EU + 3 EFTA countries (Iceland, Norway and Switzerland) + 2 EU candidate countries (FYROM, Turkey). Temporal coverage includes 2006 and 2009/2011. Employment (jobs) statistics are available at the NUTS2 level, but not available at the 1 km-grid reference level. Job data are provided for the location where people live, and do not take commuters into account. Thus, in order to improve accuracy, we corrected the data with commuting information. In addition, not all jobs are full-time positions. Part-time workers use the built-up areas for less time than full-time employees. In order to reflect this difference in utilisation density, full-time equivalents were considered to present a more reliable picture of LUP. The correction factor for full-time equivalents was derived from data on full-time equivalents for Switzerland in the year 2000/2001. However, this factor can be further adjusted for different countries based on national datasets (if available).

Fig. 4. Example of ESTAT GEOSTAT population grid for 2006 (left) and 2011 (right). The more the colour tends to red, the higher the population.

Fig. 5. Results of Weighted Urban Proliferation (WUP, measured in urban permeation units) based on different reference units (from left to right): NUTS0, NUTS2, 1 km² grid.
Reference units
Two levels of spatial reference units were used providing a multi-scale description of urban sprawl status and changes.

- NUTS-0, NUTS-2 – the Nomenclature of Statistical Territorial Units (NUTS) divides the territory of the European Union into a hierarchical system of spatial units, which facilitates the collection of regional statistical and other information for socio-economic analyses and the framing of policies. NUTS-0 represents the country level, while NUTS-2 represents the level of regions/provinces/states/prefectures with a population between 800,000 and 3 million. The NUTS classification has changed over time since its introduction at the end of the 1990s. Some regions have been split, merged, or renamed, which complicates the comparison between different points in time. In order to facilitate such comparisons, the NUTS-2 regions in their delineation of 2010 were used in the present project. Population values and other variables for 2006 were adjusted to 2010 for those regions where the delineation changed between 2006 and 2010.

- 1 km (LEAC) grid – The Land and Ecosystem Accounting (LEAC) is an EEA-maintained approach to assess ecosystem properties and functions that play an important role in policy making at the regional scale. The LEAC grid is based on the European reference grid used for activities in the frame of LEAC and has a resolution of 1 km².

2.3 Technical implementation

The calculation of urban sprawl indicators at the pan-European level is obviously not only a challenging task generally, but also from a processing point of view. Thus, specific activities consisted of optimisation of the whole processing chain in order to streamline calculations. This was achieved through strong cooperation with other ETC partners (University of Malaga (UMA) and FOMI Hungary). All calculations were performed remotely using the Mass Computing Facilities at the University of Malaga, which enabled parallelisation of the entire computation.

Fig. 6. The schema of the complete processing chain and screenshot of its implementation in the ArcGIS Toolbox (right).
to support regional or country-level needs for urban sprawl measurements. A dedicated Urban Sprawl Metric calculation tool is implemented in the standard ArcGIS Toolbox. This tool is available for free to all interested users in order to promote WUP-related urban sprawl metrics testing and implementation.

2.4 Results

The Urban Sprawl in Europe project applied the above described method of measuring urban sprawl to 32 countries across Europe. Due to a pending HRL Imperviousness data update release for 2012, for the time being only figures for the reference years 2006 and 2009 are available. The results are presented as maps, tables or graphs, together providing insight into the urban sprawl situation in Europe. In addition, relationships with twelve potential drivers of urban sprawl were statistically analysed.

The results show that large parts of Europe are affected by urban sprawl. The total value of WUP for Europe is 1.57 UPU/m² for 2006 and 1.64 UPU/m² for 2009. While a general significantly increasing trend across Europe between 2006 and 2009 was found (Fig. 7), large differences between individual countries can also be observed (e.g., 0.11 UPU/m² in Iceland and 6.5 UPU/m² in Belgium).

As seen in figure 8, high heterogeneity also exists within most countries. Yearly increases in WUP range between 0.2 %/y and 11 %/y. Nevertheless, WUP has still increased in all countries, and also in 89 % of the NUTS2 regions.

The method described here works well for the purpose of comparing WUP and its components between regions and between different points in time, and all three scales (NUTS0, NUTS2, 1 km² grid) prove to be important for effective comparisons. At finer scales, more detail and heterogeneity become visible.

3 Conclusions

The Urban Sprawl in Europe project successfully implemented WUP measures at the European level. Results show that the method works well and provides a harmonised basis for comparative purposes using Europe-wide datasets. The project represents the first analysis of urban sprawl and its temporal change for an entire continent. The implementation of the present urban sprawl methodology for Europe is also operational since a) it is based on regular dataflows from Copernicus and Eurostat, which are regularly updated, and b) the computational infrastructure and c) the overall workflow are already prepared for regular WUP updates. In addition to its application at the pan-European level, regional or country-level urban sprawl metrics calculations are supported via the dedicated free Urban Sprawl Metric calculation tool implemented in the standard ArcGIS Toolbox.

In conclusion, monitoring sprawl using the WUP method enables the comparison of the current situation in urban sprawl across the Europe, helps to identify trends, and supports the forecasting of future scenarios. Overall, the method makes the debate on urban sprawl in Europe more objective, and, in the long run, supports monitoring mechanisms that will enable accurate performance evaluations of measures taken to reduce urban sprawl.
Fig. 9. Weighted Urban Proliferation (WUP) comparison on all three spatial scales (NUTS0, NUTS2, 1 km² grid) mapped.
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4 Literature


Abstract

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Land, as a hidden and finite resource that sustains every aspect of our society, requires efficient use. Limiting overall land take and proper management of urban sprawl patterns are being recognised as increasingly urgent at the European level, and goals and options for EU contributions to a more sustainable management of land as a resource are currently being discussed. Thus, at the EU level, a number of milestones are proposed regarding land and soil that reflect Rio+20 global ambitions and related targets that are already supported by many EU policy instruments. Even though the great importance of the problem is now recognised, to date there is no regular monitoring of land consumption and urban sprawl in place at the European level. The ongoing research project entitled Urban Sprawl in Europe aims to measure urban sprawl in Europe and contribute to filling this gap. This article provides an overview of the main elements of the application of new urban sprawl measures at the European level, the strategy used for their implementation, as well as the first results.

Keywords: urban sprawl, land take, resource efficiency, landscape metric, Copernicus services, weighted urban proliferation (WUP)

Zusammenfassung

Anwendung des neuen GIS-Tools zur Messung der Zersiedlung in Europa


Schlüsselwörter: Zersiedlung, Landverbrauch, Ressourceneffizienz, Landschaftsstrukturmasse, Copernicus Projekt, gewichtete Zersiedlung, WUP