Ecological Indicators 36 (2014) 315–323

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original article

Urban sprawl scatterplots for Urban Morphological Zones data

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ARTICLE INFO

Article history:
Received 27 August 2012
Received in revised form 2 July 2013
Accepted 11 July 2013

Keywords:
Urban sprawl
Moran's *I*
CORINE Land Cover
Area-proportionately additive
Landscape metrics
Fragmentation
Northern Italy

ABSTRACT

Urban sprawl is defined as an inefficient urban development often linked to sparse building density over rural areas. Routinely available remote sensing data on land cover are useful to study such phenomena, focus is on large raster maps of Urban Morphological Zones (UMZ) produced by the CORINE Land Cover programme of the European Environmental Agency. We present statistical indices to investigate changes in urban size and morphology between sub-regions within a predefined study area and show their implementation with raster data representing UMZ. Urban size is measured by urban land proportion, while morphology is quantified by Moran's *I* spatial correlation index. These two area-proportionately additive measures allow comparisons between urban size and morphology in sub-regions of different size to be performed. An urban sprawl scatterplot displaying Moran's *I vs.* urban land proportion is proposed as a tool to compare the urban sprawl level in pre-defined sub-regions with respect to a global average level. This scatterplot allows urban sprawled regions within a map to be identified and also an assessment of whether sprawl is due to augmented urban size or decreased urban compactness. An example of the methods is given for Bologna province, Northern Italy, where the interest is in detecting types of urban sprawl at several spatial scales, i.e. municipalities and unions of municipalities, within the whole province.

1. Introduction

"Landscapes are the setting for all human activities, providing a home to humans and all other life forms. Landscapes change constantly but in recent decades humans have often shaped them with little thought to the cumulative impacts and at a pace that is unprecedented. The value of landscapes is not yet fully reflected in decision-making on transport infrastructure and urban development" (EEA, 2011a). The development and expansion of urban patterns is a main driver of landscape fragmentation.

The spatial configuration and the dynamics of urban growth are important topics in the analysis of contemporary urban studies, including urban sprawl as a specific kind of urban growth, or development. Urban sprawl is an important issue for biologists, urban specialists, planners and statisticians, and also for official statistics, as rapid and uncontrolled urban expansion in the world is alarming, both in developed and developing countries. Several authors have addressed these issues with or without the consideration of demographic process and urbanisation (Bhatta et al., 2010).

A universally accepted, well established definition of urban sprawl does not exist, but one of its fundamental abilities must be to capture uncontrolled and inefficient urban dispersion, accompanied by low building and population density, over rural or semi-rural areas, likely to be mainly found in peripheral areas, cities' most recent and changing sectors. Urban sprawl usually occurs when urban planning is not well managed, turns open spaces into built spaces, and, as a long term consequence, leads to negative effects on the environment, in particular soil sealing and pollution.

Information about unplanned settlements in developing cities is often unavailable, due to their rapid development and capacity constraints of planning authorities to keep track. There are still very few tools to assist in the identification of unplanned areas as well as monitoring their development (Kuffer and Barros, 2011). Therefore, there is a clear need for such tools to be used with spatial databases from remote sensing data.

Several spatial metrics can be used for quantifying features concerning the morphology of urban settlements, analysing certain characteristics of the spatial pattern such as, for instance, the degree of continuity, concentration, clustering, centrality and nuclearity; see Tsai (2005), Jaeger et al. (2010b) and Bhatta et al. (2010) for a discussion of the sprawl dimensions involved in the characterization of the urban morphology. Many spatial indices have been proposed in the literature for remote sensing data, where each index typically focuses on quantifying a specific aspect among those

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http://dx.doi.org/10.1016/j.ecolind.2013.07.011

mentioned above. Jaeger et al. (2010b) emphasize the fundamental role played by both *urban size* and *urban morphology* in characterizing urban sprawl: "urban sprawl is visually perceptible [. . .], the more urban area present in a landscape and the more dispersed the urban patches, the higher the degree of urban sprawl". Urban size can be generally defined as the amount of urban land take in a study region. Urban morphology can be regarded as the spatial pattern of urbanization in that region. The definition of urban sprawl that we assume throughout this paper is based on both dimensions of urban size and morphology. Specifically, we assume that (*a*) the more an area is urbanized and (*b*) the more urbanization is sparsely distributed over space, with the urban pattern diverging from a compact and circular shape, the more the urban sprawl phenomenon is relevant in that area.

In Jaeger et al. (2010b), 13 suitability criteria to be considered in evaluating the consistency of urban sprawl indices are introduced. Among those criteria, we shall focus on two desirable mathematical properties for an urban sprawl index:

1. *Mathematical homogeneity*. This property regulates the behaviour of an urban sprawl measure in the situation where the analysed region is enlarged while the spatial urban pattern remains the same. According to this property a measure can be *intensive* or *extensive*. A measure is called intensive if it remains constant when evaluated in an enlarged size region with unchanged pattern, whereas it is extensive if it increases by the same factor the region is multiplied by.
2. *Additivity*. This property regulates the behaviour of an urban sprawl measure reported at different spatial scales, for instance when its value is required for the union of two regions rather than for just the single regions separately. According to this property a measure can be *additive* or *area-proportionately additive*. When the value for the union of two or more regions equals the sum of the values for the single regions a measure is called additive. When the value for the union of two or more regions is the weighted average of the values for the single regions, with weights proportional to their size, a measure is called area-proportionately additive (hereafter denoted as *apa*).

A useful aspect of an intensive urban sprawl index (property 1) is that it allows the degree of sprawl of different size regions to be compared, with guarantee that any divergence in the index value is attributable to a real sprawl effect and not to the changed scale. A useful aspect of an *apa* urban sprawl index (property 2) is that it allows the contribution of each sub-regions to the degree of sprawl of the entire region to be calculated, or, alternatively, the degree of sprawl of the entire region to be computed on the basis of the sprawl values calculated in the sub-regions. Furthermore, as Jaeger et al. (2010b) pointed out, an *apa* measure is also intensive, while an intensive indicator is not necessarily *apa* too. Therefore, we can argue that an urban sprawl indicator which satisfies the apa property yields two benefits: first, it allows comparisons of the degree of sprawl in a certain sub-region with an appropriate reference value, e.g. the degree of sprawl in the entire region (local *vs.* global); second, it allows comparisons of the degree of sprawl between sub-regions with different size (local *vs.* local). Urban sprawl measures which enjoy the *apa* property are not common in the literature. Also, the development of urban sprawl indices for high spatial resolution data, such as raster maps, is uncommon.

This paper has two methodological purposes. The first purpose is to jointly account for urban size and morphology in the evaluation of urban sprawl and to measure both dimensions of sprawl by using *apa* statistical indicators. As a measure of urban size the urban land proportion p is used. For measuring the degree of compactness of the urban morphology several measures have been adopted, often by adapting spatial metrics commonly adopted by landscape ecologists (Bhatta et al., 2010). Two popular spatial metrics for urban sprawl are the proximity index (Gustafson and Parker, 1992) and the contagion index (McGarigal et al., 2012; Torrens, 2008). Both are intensive measures, but are not *apa* (Jaeger et al., 2010b). It is important for an urban sprawl measure to maintain both these properties; see Jaeger et al. (2010a) for a proposal of an urban sprawl measure which is both intensive and area-proportionately additive. In this work we apply Moran's I spatial association index (Moran, 1948) to raster data in order to measure urban morphology as the degree of compactness of the observed pattern. The *apa* property is immediate for the urban land proportion p, while it will be demonstrated analytically for Moran's I.

The second purpose of this paper is to adapt the calculation of the proposed indices to large raster datasets, such as maps produced routinely by CORINE Land Cover programme (EEA, 2011a). Rasters give a clear advantage in terms of a fine representation of the spatial pattern of urbanization. The computational cost especially in the evaluation of Moran's I can be relevant though, even in a moderately large study area. Efficient algorithms to compute Moran's I while reducing the computational burden are needed and one proposal is presented in this work.

The practical contribution of the paper is a graphical tool, hereafter named the *urban sprawl scatterplot*, which allows the detection of urban *sprawled* areas within a study region. The scatterplot displays Moran's I against urban land proportion p and permits a joint evaluation of urban size and morphology. The approach proposed is based on comparisons: our aim is an evaluation of local values of the degree of sprawl relative to a global reference value. In other words, the assessment of the degree of urban sprawl in certain sub-regions of interest will be performed with respect to (w.r.t.) a global average, referred to a wider region such as, for instance, the entire study-region. One important feature of the scatterplot is the ability to distinguish between two "types of sprawl" the sub-regions can be affected by: augmented urban size or decreased compactness.

As an illustration of the proposed method, we analyse raster data from CORINE for the area of Bologna province, where an administrative re-organization is currently underway, and which is an outstanding case study for detecting urban sprawl. Comparisons will concern pre-defined sub-areas over the study region, in particular, the focus will be on comparisons between municipalities and between/within groups of neighbouring municipalities over the Bologna province.

2. Methods

2.1. Spatial data

Spatial data are derived from official sources as we wanted to handle harmonised and official datasets to study urban sprawl at a large scale. CORINE Land Cover provides data collected from nearly all EU countries and consists of vector categorical data, with a total of 44 land cover classes. These data are available as raster data at two resolution levels: the coarser assumes a grid with pixel size of 250 m, while the finer of 100 m. Notice that these raster data are independent, i.e. data at the coarser resolution are the result of a separate rasterization process, they are not resampled from the finer resolution dataset.

In 2011, a binary raster dataset relative to land cover data collected in 2000 was also published (EEA, 2011b). This dataset is the result of separating the original land cover raster data into urbanised and non-urbanised zones. Land cover classes that contribute to the urban tissue (urbanized zones) and involve urban functions are: continuous urban fabric, discontinuous urban fabric, industrial or commercial units and green urban areas. These