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Methods for specifying spatial boundaries of cities in the world: The impacts of delineation methods on city sustainability indices

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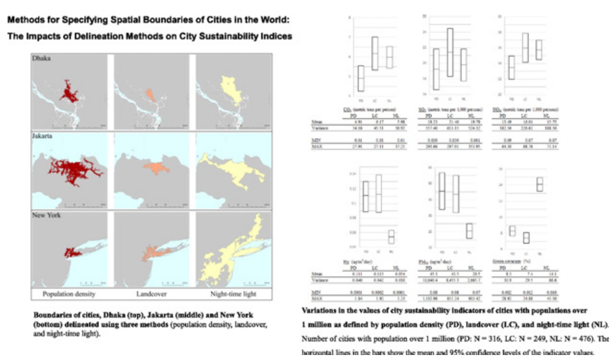
HIGHLIGHTS

- No definition of a city is commonly shared in some different academic fields.
- We propose a method to delineate boundaries of cities based on population density.
- Practical methods based on the density, night-time light and landcover are compared.
- Difference in urban indicators is due to difference in method of specifying a city.
- Relevant definitions of cities should be chosen for policy making based on its aim.

GRAPHICAL ABSTRACT



Boundaries of cities, Dhaka (top), Jakarta (middle) and New York (bottom) delineated using three methods (population density, landcover, and night-time light).

Variations in the values of city sustainability indicators of cities with populations over 1 million as defined by population density (PD), landcover (LC), and night-time light (NL). Number of cities with population over 1 million (PD: N = 316, LC: N = 249, NL: N = 476). The horizontal lines in the bars show the mean and 95% confidence levels of the indicator values.

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ABSTRACT

The purpose of this paper is to analyze how different definitions and methods for delineating the spatial boundaries of cities have an impact on the values of city sustainability indicators. It is necessary to distinguish the inside of cities from the outside when calculating the values of sustainability indicators that assess the impacts of human activities within cities on areas beyond their boundaries. For this purpose, spatial boundaries of cities should be practically detected on the basis of a relevant definition of a city. Although no definition of a city is commonly shared among academic fields, three practical methods for identifying urban areas are available in remote sensing science. Those practical methods are based on population density, landcover, and night-time lights. These methods are correlated, but non-negligible differences exist in their determination of urban extents and urban population. Furthermore, critical and statistically significant differences in some urban environmental sustainability indicators result from the three different urban detection methods. For example, the average values of CO_2 emissions per capita and PM_{10} concentration in cities with more than 1 million residents are significantly different among the definitions. When analyzing city sustainability indicators and disseminating the implication of the results, the values based on the different definitions should be simultaneously investigated. It is necessary to carefully choose a relevant definition to analyze sustainability indicators for policy making. Otherwise, ineffective and inefficient policies will be developed.

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1. Introduction

According to UNDESA (2012), 3.6 billion people of the 7.0 billion world population live in urban areas, and the urban population is projected to increase to 6.3 billion while the world population will be 9.3 billion in 2050. This projection implies that the entire increase in the world population will be absorbed by urban areas. In addition, even in the less developed regions, the urban population is expected to be dominant in 2050, with 64% of the population living in urban areas (UNDESA, 2012). Considering the size of the urban population, we cannot ignore the impact that human activities in cities have on societies, economies, and the environment in terms of sustainability.

A city is an important entity for sustainable development in environmental, economic, and social dimensions. Cities are engines of economic development. One of the reasons that cities exist is that they foster prosperity (UN-Habitat, 2013). The main reason for the existence of cities is the benefits from their agglomeration effects such as scale of economy, positive externality, accumulation of labor force, and spillover effects of knowledge (Henderson, 1974; Segal, 1976; Krugman, 1993; Saxenian, 1994; Camagni et al., 1998; Munda, 2006). On the other hand, urban areas attract poor people from rural areas, and slums then expand in the peripheral areas of cities (UNFPA, 2011). In this respect, we should simultaneously assess both economic prosperity and socio-economic disparity. Furthermore, the impacts of cities on the long-term sustainability of local and global environments are critical (Baumgärtner and Quaas, 2010). For example, research on the impact of urbanization on the amount of CO_2 emissions has been conducted, although decisive conclusions have not been provided (Poumanyvong and Kaneko, 2010; Martínez-Zarzoso and Maruotti, 2011). On the other hand, the impact of climate change due to the emissions of greenhouse gases on urban areas has also been discussed (World Bank, 2010; UN-Habitat, 2011).

Considering the urban issues described above, it is critically important to explicitly evaluate the sustainability of cities in the three dimensions (environmental, economic, and social), the so-called 'triple bottom line' (Elkington, 1997). In so doing, we need to create a City Sustainability Index (CSI) (Mori and Christodoulou, 2012; Mori and Yamashita, 2015). In fact, many alternative lists of urban sustainability indicators have been provided (Haghshenas and Vaziri, 2012; Wang et al., 2013; López-Ruiz et al., 2014; Pires et al., 2014). For example, Shen et al. (2011) examined and compared nine different lists of urban sustainability indicators used in nine different regions (cities), and derived a primary list of urban sustainability indicators based on the comparison. One of the most significant requirements for CSI is to measure and assess leakage (i.e., spillover) effects of cities on neighboring areas, because cities depend on areas beyond their boundaries for such things as the supply of resources and food, the disposition of wastes, the emissions of pollutants, and the indirect use of ecosystem services (Morse and Fraser, 2005; Mayer, 2008; Mori and Christodoulou, 2012). Cities are essentially non-sustainable in the environmental dimension (Bithas and Christofakis, 2006). Considering these characteristics, city sustainability should be assessed for comparing cities, and the definition of cities should be carefully chosen so that their spatial extent can be clearly detected in a practical manner.

However, no definition of a city is commonly shared despite the fact that the urban population is large. Under this circumstance, creating a meaningful and operational definition of urban areas is a significant problem that remains to be solved (Potere and Schneider, 2007). National governments and municipalities define urban areas in numerous ways and the boundaries of these areas can change for political, demographic or economic reasons (UNFPA, 2011). Thus, urban populations may be counted in different ways depending on which definition of urban areas is used (UNFPA, 2011).

In academic terms, the definition of city boundaries differs among researchers and academic fields, as illustrated by the following examples. In some instances, urban areas are delineated by built-up areas, impervious surface, built environment, or developed areas (Potere et al., 2009; Bagan and Yamagata, 2012; He et al., 2015; Bathrellos et al., 2017). In the field of urban ecology, urban areas are defined qualitatively, i.e., areas under human influence (Mcintyre et al., 2000; Marcotullio and Solecki, 2013). Social scientists use the term 'urban' to refer to areas with high human population density (Mcintyre et al., 2000). Wirth (1938) provides three conceptual factors of cities that describe or define the characteristics of cities: size of population, density, and heterogeneity. Uchiyama and Mori (2014) use a workable demarcation of urban boundaries based on the grid data of population density to highlight the inconsistencies that exist in an important database showing per capita gross domestic product (GDP) in urban and non-urban areas. Politically administrated boundaries of cities are not useful for sustainability assessment from the theoretical point of view because the boundaries are arbitrarily determined by individual governments (Bell and Morse, 2008; Mayer, 2008; Graymore et al., 2010). Indicators for cities are, however, mostly provided on the basis of political boundaries such as Green City Index (Siemens, 2012; Meijering et al., 2014) and the City Development Index and Global Urban Indicators (UN-Habitat, 2001).

Different definitions and identification methods provide different boundaries for the same cities, and thus population size, population density and components of land cover for any given city will differ considerably depending on the methodology or definition used to define the boundary. The results of sustainability assessment may be influenced by the differences. Therefore, the precondition for measuring the values of sustainability indicators is to delineate the spatial boundaries of cities based on a relevant definition that is appropriate for a specific purpose of research. Christenson et al. (2014) compared the assessment results of water quality in urban areas in a country, using different definitions of urban area. These researchers suggested that the values of urban indicators are affected by the choice of urban area definitions, which is not trivial. This type of comparative analysis, however, has not been sufficiently performed up to now.

The purpose of this paper is to analyze how different definitions and identification methods for urban areas affect the values of city sustainability indicators. Three major practical methods based on population density, landcover, and night-time lights are examined. Before the comparative analysis of the methods, a brief literature review on definitions of a city is provided.

2. Review about definitions of cities

In this section, we review definitions of cities in three academic fields: (1) remote sensing science, (2) urban ecology, and (3) social science. We find that no tractable definition of cities is commonly shared among these disciplines.

2.1. Remote sensing science

In this research field, several definitions and corresponding methods for delineating boundaries of cities have been developed, but no definition and no method is commonly shared. Built-up areas and night-time lights are often used in remote sensing science to detect boundaries of cities (Potere et al., 2009; Bagan and Yamagata, 2012). Improved accuracy in mapping built-up or developed areas is the major goal of the line of research. The methods have diverged to a large extent, and as a result, are inconsistent in defining the ratio of urban areas to the total land surface (Potere and Schneider, 2007). The methods used for mapping built-up areas have aimed to enhance the resolution of the map (Weng, 2012; Giri et al., 2013). Night-time lights also have been utilized to identify the urban extent (Zhang and Seto, 2011; Levin and Duke, 2012). However, determining the threshold intensity of night-time