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Spatiotemporal urban expansion in Pune metropolis, India using remote sensing

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ABSTRACT

Indian cities are expanding at an unprecedented rate. The speed of development poses a challenge for urban planners, as the expansion of cities frequently outpaces the planning process. This leads to further challenges for urban planners, namely i) the database for the planning is often outdated and ii) processes and patterns of unplanned urban growth are not accounted for appropriately. This paper presents an approach to address these challenges by utilizing generally available and inexpensive remote sensing data to study i) the land use and land cover change and ii) by analyzing the extent of urban areas to study the patterns and processes of urban growth. We assesses land-use/land-cover for three years (1992, 2001, 2013) using multi-temporal Landsat datasets. A detailed spatiotemporal analysis of urban expansion and typologies of urban growth at the scale of individual administrative units. The dynamics of urban growth was quantified using different metrics of urban expansion. Three types of urban expansion patterns were identified in the Pune metropolis, i) coalescence phase of urbanization in the main city areas, ii) diffusion phase in the suburbs and iii) marginal growth in the cantonments. The overall process of urban expansion in the Pune metropolis can thus be referred to as a diffusion–coalescence pattern. Furthermore, our results show that the speed of the urban expansion in the Pune metropolis area has doubled from 2001 to 2013 as compared to 1992–2001. Urban land has increased at the cost of grasslands, barren and agricultural lands. The percentage of change is high in the suburbs under semi-urban and village council jurisdictions, whereas in terms of total growth, areas under the municipal corporation jurisdictions are among the highest contributors to urban expansion. Administrative units governed by cantonment boards have shown marginal growth as compared to the civil administrative units in the study area.

1. Introduction

Urbanization is a physical and socio-economic spatiotemporal process that transforms the rural landscape into urban form (Han, Hayashi, Cao, & Imura, 2009; Thapa & Murayama, 2010). It is manifested in the expansion of built-up area in terms of houses, industry or infrastructure within or in direct connection to an urban area (Ge & Cao, 2009; KantaKumar, Sawant, & Kumar, 2011). Today, urban areas occupy only five percent of the earth's terrestrial surface but they are home to almost half of the global population, who consume seventy-five percent of the world's natural resources and generate an equivalent proportion of pollution and waste (Netzband, Stefanov, & Redman, 2007). Urbanization involves conversion of natural and semi-natural surface cover into impervious surfaces (Li, Zhou, & Ouyang, 2013; Taubenböck, Wegmann, Roth, Mehl, & Dech, 2009). Thus, unless managed properly it often leads to serious ecological and environmental degradation such as reduced green spaces, increased land fragmentation, decreased air and water quality, loss of fertile agriculture land and alteration of natural drainage (Grimm, Grove, Pickett, & Redman, 2008; Li et al., 2013; Li & Yeh, 2000; Mage et al., 1996; Pickett et al., 1997).

Urban India is experiencing land-use and land-cover change at an unprecedented rate. The United Nation's report on world urbanization prospects (2011) states that half of India's population will live in cities by 2050 (United Nations, 2012). During this period, India will witness a major historical rural to urban transition.

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Several cities in India are experiencing the negative effects of urbanization (Gupta & Kumar, 2006; Kandlikar & Ramachandran, 2000; Kumar et al., 2009; Sudhira, Ramachandra, & Subrahmanya, 2007). However, urbanization fosters economic growth of a nation. Presently urban India accounts for sixty three percent of the Indian GDP and is expected to increase to seventy five percent by 2030. Cities are thus considered the economic engines of a nation (Planning Commission, 2012). Therefore, the focus of policies should be to prevent unsustainable urbanization rather than attempt to slow or reverse it (Duranton, 2009; Spence, Annez, & Buckley, 2009). The rapid urbanization in India is a challenge for Indian city planners as the expansion of urban areas outpaces the planning process as well as the development of infrastructure. A major challenge confronting the Indian government thus is to generate sufficient infrastructure to accommodate the needs of 484 million additional urban dwellers by 2050 (Swerts, Pumain, & Denis, 2014). An accurate assessment of the state of current urbanization and the formal and informal processes leading to urban expansion is thus necessary to ensure sustainable urban expansion and to mitigate adverse ecological and environmental impacts. Tools to measure, monitor and understand the urban expansion process are thus key to urban planners. Accurate information about the state of urbanization, the rate of urban expansion, and the patterns and extent of sprawl is often not available in a timely manner. However this information is needed by planners to provide for the services required by the urban population (Ma & Xu, 2010; Taubenböck et al., 2009).

Remote sensing provides both spatially and temporally consistent data to map and monitor the spatiotemporal dynamics of urban expansion (Herold, Goldstein, & Clarke, 2003; Xiao et al., 2006). When used in conjunction with geographical information systems (GIS), it provide an efficient and cost effective approach to monitor and understand urban expansion (Angel et al., 2005; Bhatta, 2009; Fan, Wang, Qiu, & Wang, 2009; Hu, Du, & Guo, 2007; Jat, Garg, & Khare, 2008; Masser, 2001; Seto, Fragkias, Güneralp, & Reilly, 2011; Wakode, Baier, Jha, & Azzam, 2014; Xiao et al., 2006; Xu et al., 2007). Analyzing historical urban expansion can reveal the dynamics, processes and types of urban expansion and help to manage complex urban development effectively (Geymen & Baz, 2008; Masek, Lindsay, & Goward, 2000). Since, urban expansion results in land-use and land-cover change (LUCC), a detailed LUCC inventory is necessary to study and understand urban expansion processes.

To quantify urban expansion different metrics are used in the literature. Sudhira, Ramachandra, and Jagadish (2004) used Shannon entropy, patchiness and built-up density in conjunction with regression analysis to quantify and model the urban sprawl of Mangalore–Udipi region of India. Kumar, Pathan, and Bhanderi (2007) and Jat et al., (2008) used land scape metrics and Shannon entropy to monitor the urban expansion of Indore and Ajmer cities respectively. Taubenböck et al., (2009) used spatial metrics such as built-up density, landscape shape index, largest patch index, number of patches, total edge and edge density to capture the spatiotemporal urban form of 12 most populous Indian cities.

In addition to quantitative measures of urban growth, qualitative measures describing the processes and types of urban development are needed to understand the urban growth process. Thus, a detailed spatiotemporal assessment of different types of urban growth at the level of individual administrative units is necessary to provide planners with data needed in the planning process. This data will not only help planners to identify regions undergoing rapid urbanization; it is also indicative to understanding policy implication upon the growth process, the balance between planned and spontaneous development and it is needed to assess impacts of urban growth upon the environment. This knowledge is essential to design better policies to manage urban development and to reduce undesired effects of urbanization. However, studies combining both, a quantitative assessment of urban growth and qualitative information of the urban growth process for an Indian metropolis at the scale most relevant to urban planning which are individual administrative units, is still missing.

Our research was done for the Pune metropolis. This area is one of the fastest growing incipient Indian mega city and has attracted most of the Special Economic Zones (SEZ) in last decade. The areas under the Pune metropolis are governed by different administrative authorities viz., municipal corporations, municipalities, cantonment boards and village councils. It makes Pune a unique metropolis among the other Indian cities. This paper presents both: i) quantitative information on the growth of Pune provided by a detailed analysis of urban expansion and ii) qualitative information on the urban expansion process by providing a typology of expansion differentiating expansion in the urban core, the fringe, ribbon development and scatter development in individual administrative units.

Our analysis is based on LANDSAT satellite images acquired between 1992 to 2013, thus encompassing the period of rapid urban development in Pune.

The objectives of the present study are:

i. To quantify the spatiotemporal changes in land-use/land-cover driven by the urban expansion between 1992–2001 and 2001–2013.
ii. To quantify and analyze the urban expansion, which leads to
iii. A typology of urban development processes for every administrative unit of the study area in last 21 years.

2. Study area

The Pune metropolis is located on the Deccan plateau at the foot of the northern part of the Western Ghats. The study area is composed of i) two municipal corporations, Pune (PMC) and Pimpri-Chinchwad (PCMC), ii) one municipality Talegaon-Dabhade (TD), iii) three cantonment boards namely, Kirkee (KCB), Pune (PCB) and Dehu (DCB) and iv) the surrounding outgrowth towns and villages under the administration of semi-urban and village councils in Haveli and Mulshi (Fig. 1). The region is bounded by the ridges of Western Ghats in the south and the west, by the Indrayani River in the north and by Daund tehsil in the east. Two rivers, Mula and Mutha drain through the center of the study area. The Pune metropolis is located between the 18°19′ to 18°45′ north of equator and 73°35′ to 74°12′ east of Greenwich encompassing an area of 1643 km^2. The study area is located at about 550 m above the mean sea level and has a mean annual temperature of 25 °C with a mean annual precipitation of 741 mm.

Pune the cultural capital of the state of Maharashtra is home to many premier industries in manufacturing, automobile, information and biotechnology. In 1960, the Maharashtra Industrial Development Corporation (MIDC) established an industrial estate in the PCMC that has transformed small villages into a major industrial hub in India. Since the introduction of Foreign Direct Investments (FDI) in 1991, the region has been witnessing fast industrialization and urbanization. The adoption of special economic zone policy by the state of Maharashtra in 2006 has further boosted the economic growth of the region (Government of Maharashtra, 2013). The population of the study area grew from 2.6 million in 1991to 4.3 million in 2001 and 5.9 million in 2011 (Fig. 2) (Census of India, 2011).