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Vegetation change and fragmentation in the mega city of Delhi: Mapping 25 years of change

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ABSTRACT

Delhi, the worlds' second most populous city, has experienced rapid, planned and unplanned expansion at the cost of its green cover in recent decades. In this study, we use satellite images from 1986, 1999 and 2010 to map changes in urban and green cover, assess the fragmentation of green spaces, and identify the drivers of change. We find that urban patterns of development have shaped the distribution and fragmentation of green spaces, with the city center containing more green spaces with less fragmentation compared to intermediate areas and the peri-urban periphery. Yet, the city core has also experienced the greatest degree of vegetation clearing and fragmentation over time due to infrastructural expansion, while the peri-urban periphery has shown an increase in vegetation and a decrease in fragmentation due to recent compensatory plantation in these peripheral areas. Forests, archaeological sites, and military and academic campuses have played a major role in protecting green cover and limiting fragmentation in the core and intermediate areas of the city. This research helps in advancing our understanding of the pattern–process relationship between urbanization and land cover change/fragmentation in India's largest city.

Introduction

Urban green spaces constitute one of the most significant assets of a city, providing relief in stressed urban environments (Elmqvist et al., 2013). With more urban densification, the few remaining green spaces in urban areas are becoming increasingly significant refuges for urban biodiversity (Goddard, Andrew, Dougill, & Benton, 2010). Urban vegetation provides various ecosystem services including air purification, water infiltration, reduction in water pollution, micro-climate regulation, noise reduction and carbon sequestration (Kong, Yin, & Nakagoshi, 2007). Urban green spaces also provide critical places that connect people to nature, provide environmental education, and play an important recreational, spiritual, therapeutic and cultural role in the lives of city residents (Bolund & Hunhammar, 1999). Green cities contribute to increased urban sustainability, and towards human wellbeing (Arnberger, 2006; Bennett, Peterson, & Gordon, 2009; Bolund & Hunhammar, 1999).

Yet despite their importance, urban green spaces are at increasing risk, shrinking in area and experiencing fragmentation and loss in connectivity due to increasing demands for urban expansion and the increased intensity of the urban footprint in and around cities (Seto, Güneralp, & Hutyra, 2012). Their distribution is spatially irregular and driven by various biophysical, ecological, social and economic forces (Pickett et al., 2001). Accurate knowledge of the factors driving changes in the extent, location and distribution of green spaces is important to help city planners design better policies for conservation of urban green spaces. Satellite images are an excellent data source for accurate and extensive monitoring of green cover, providing repetitive coverage at high spatial resolution, with easy availability (Jim & Chen, 2003; Kendal, Williams, & Williams, 2012; Nagendra, Nagendran, Paul, & Pareeth, 2012). Further, the ability of remotely sensed data to be easily integrated into a geographic information system (GIS) along with

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other datasets for spatial analysis has greatly facilitated urban studies (Wentz et al., 2014).

Monitoring of urban green spaces is a particularly important challenge for Asia, which contains some of the world's densest and fastest growing cities. Asian cities are projected to account for over half of the anticipated global increase in urban cover in the coming two decades, with green spaces particularly at risk (Seto et al., 2012). India is projected to account for the greatest fraction of this change, with Indian cities anticipated to add over 400 million people by 2050 (United Nations, 2014).

Delhi, India's capital city, has experienced rapid, planned and unplanned expansion at the cost of its greenery leading to large scale impacts on the city's ecosystem services and biodiversity. In this study, we use satellite images from 1986, 1999 and 2010 to map changes in urban and green cover, assess the fragmentation of green spaces, and identify the drivers of change in green space in Delhi amidst rapid urbanization. In the present study urban green space includes land that is partly or completely covered with trees and shrubs.

We focus on two issues. First, recent studies of Indian cities (summarized in Nagendra et al., 2012) suggest that urbanization in India may follow a pattern of growth that is somewhat different from what is observed in North American cities. Specifically, high land prices in the city center may lead to plateauing of urban growth and protection of green spaces in the center, while peripheral areas face rapid change with loss of vegetation area coupled with fragmentation of connectivity. This needs to be better understood, as such differences can shape the focus of urban planning and policy. Second, there is a lack of sufficient focus of urban policy on urban greening, globally as well as in South Asia (United Nations, 2014). Indian cities like Delhi are shaped by their history as former colonial settlements, with large campuses that continue to be managed by various governmental agencies. The effect of these public institutions on the protection and maintenance of urban green spaces needs to be better understood (Nagendra et al., 2012), as these represent locations where interventions for greening are perhaps most feasible for urban policy.

Following from this, we examine the role of the two factors identified above in driving changes in urban green spaces and fragmentation (a) the impact of urban development in shaping differences in the extent and fragmentation of green spaces between the city center, intermediate and peripheral areas and (b) the role of public institutions in protecting green cover and limiting fragmentation. This study advances our understanding of the pattern–process relationship between urbanization and land cover change/fragmentation in India's largest and the world's second-largest city.

Materials and methods

Study area

The National Capital Territory of Delhi (NCTD) is located between 28°24′17″N and 28°53′00″ N and 76°50′24″E and 77°20′37″ E (Fig. 1). It covers an area of 1490 km^2, with an elevation range from 213 to 305 m above sea level. The topography of the NCTD ranges from largely agricultural plains in the north, to the arid foothills of the Aravalli range in the south. The Yamuna river transverses the city from the north to south. The climate is humid subtropical, with long, hot summers, and brief winters with heavy fog. The annual temperature varies from about 3 °C in the winter, to about 45 °C in the summer. The monsoon season ranges from July to September, with 400–600 mm of annual precipitation. The native vegetation of NCTD is a tropical dry thorn forest (Champion & Seth, 1968).

Administratively, the NCTD is divided into 9 districts, and 27 administrative sub-divisions or tehsils. The NCTD is administered by three local bodies – (i) New Delhi Municipal Council (NDMC), (ii) Delhi Cantonment Board (DCB) and (iii) Municipal Corporation of Delhi (MCD). The population density of NCTD was 11,297 people/km^2 in 2011, and is estimated to have an annual growth rate of 1.92% (Government of NCT of Delhi).

The NCTD is dominated by urban land cover (Sharma & Joshi, 2013). Yet, despite the high proportion of urban cover and high population density, the NCTD has extensive tree cover in a number of managed green spaces, including parks, educational institutions, government and military areas, and archaeological sites (Khera, Mehta, & Sabata, 2009; Krishen, 2006). The city also harbors a wildlife sanctuary, the Asola-Bhatti sanctuary, covering an area of 19.91 km^2.

The NCTD is comprised of a juxtaposition of old and new areas. The oldest part of the city is the congested walled area of Shahjahanabad, founded by the Mughal emperor Shah Jahan in 1638. Delhi subsequently became the capital of British India in 1911. Following this, the British architect Edwin Lutyen designed the capital city of New Delhi, popularly known as Lutyen's Delhi, following a geometrical plan, with large open green spaces and wide roads that ran along the main directions of the compass (Dupont, 2004). The Delhi cantonment, built in 1914, also contained wide roads, within which bungalows and administrative buildings were located. The present day NDMC and DCB local administrative areas correspond to Lutyen's Delhi and the Delhi Cantonment areas respectively. As with many other Indian cities, Delhi is now rapidly expanding towards its periphery, with high density built-up areas in the city center, and urban sprawl towards the periphery.

Adopting the definitions used by Jain, Taubenböck, and Namperumal (2011), three zones, representing different densities of urban development corresponding to different time periods, have been identified within the NCTD (Fig. 1). The city Core represents the older part of Delhi, consisting of Old Delhi Tehsils (Karol Bagh, Pahar Ganj, Sadar Bazar, Daryaganj, Kotwali) and New Delhi Tehsils (Parliament Street, Connaught Place and Chanakya Puri). A Transitional zone (defined as 'Ring 1' by Jain, Taubenböck, and Namperumal (2011)), which represents intermediate areas of the city, is defined on the basis of density of urban built space, and proximity to core, and is represented by East Delhi Tehsils (Seelampur, Shahdara, Seemapuri, Gandhi Nagar, Vivek Vihar and Preet Vihar), as well as Patel Nagar, Rajouri Garden, Civil Lines, Model Town and Defence Colony Tehsils. The city Periphery (defined as 'Ring 2' by Jain, Taubenböck, and Namperumal (2011)) is the peri-urban outer ring of development in NCTD, containing sections of the South, South-West and North-West Tehsils of Delhi (Saraswati Vihar, Kalkaji, Punjabi Bagh, Narela, Hauz Khas, Vasant Vihar, and Najafgarh).

Methods

Three satellite images were used for analysis. No good quality, cloud free 30 m resolution Landsat TM images of the study area were available from the 1980s. Thus a 60 m resolution Landsat MSS image of 11 January 1986 was downloaded from the USGS Global Visualization Viewer (http://glovis.usgs.gov). A 30 m resolution of Landsat ETM+ image of 22 October 1999 was downloaded from the Global Land Cover Facility at the University of Maryland. A 23 m, 6 November 2010 IRS LISS 3 image was also acquired from the National Remote Sensing Agency of India. Most planted trees in Delhi are evergreen (Krishen, 2006). For the few deciduous trees found planted in and around the city, leaf-fall largely takes place after mid-January, between mid-January to March: thus there is minimal phenological variation in tree cover during the period of late-