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Developing the desert: The pace and process of urban growth in Dubai

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ABSTRACT

It is generally acknowledged that Dubai is a rapidly developing urban area which has grown to support a large human population within a hyperarid environment. However, no publicly accessible information exists concerning the rate or form of the urbanization process in Dubai. Therefore, this investigation used a time series of remotely sensed data to quantify land cover change in Dubai emirate between 1972 and 2011. A hybrid classification method accurately discriminated urban and other land covers, despite the challenging desert environment, and landscape metrics were used to quantify the spatial evolution of the emirate. The results indicate a dramatic increase in urban area, with a compound annual growth rate of 10.03% over the study period, with a peak of 13.03% during 2003–2005, making Dubai one of the fastest growing cities in the world. While the population growth rate was high, this has been outpaced by the rate of increase in urban area and the declining population density is indicative of urban sprawl. The spatiotemporal dynamics of urban growth are closely associated with prevailing local and global economic conditions and the ambitious development strategies of the government. Notable aspects of this growth include the substantial increase in vegetation and water bodies, and the unprecedented rate of construction of offshore islands. Dubai has undergone oscillating phases of urban diffusion and coalescence, but with much more rapid transitions than other cities. Superimposed on these phases are spatial patterns of development which have been recognised elsewhere, but the sequence of patterns appears unique to Dubai. This study has provided new insights into the pace and process of urban growth in Dubai. It is now important to evaluate the environmental consequences of this form of rapid urban development.

1. Introduction

Over the last decade Dubai Emirate has witnessed great economic growth resulting from rapid urbanization which has turned the desert into residential, commercial, sports and tourism projects. In addition, the offshore environment has been developed with artificial islands, such as Palm Jumairah, Palm Deira and the World Islands. Cities within a city are a particular characteristic of this Emirate, and a number of mini cities have been developed in Dubai including Dubai Festival City, Sports City, Media City, Internet City and Healthcare City. The scale of development in recent years is evidenced by the estimate that 25% of the world's construction cranes operate in Dubai (Badouri, 2007). Indeed, the rapid pace of urban growth in Dubai has attracted the attention of economists, environmentalists and urban planners. However, there is no publicly accessible information on the expansion of Dubai, likely due to a paucity of data overall and governmental restrictions on data that do exist. Therefore, the present research presents us with the opportunity to develop and apply an accurate and objective method for quantifying urban growth in order to understand the spatiotemporal characteristics of the development process in this rapidly changing landscape.

Urban development often takes place as a consequence of factors such as industrial expansion, economic prosperity and population growth (Li, Sato, & Zhu, 2003; Yin, Stewart, Bullard, & MacLachlan, 2005). Conversely, urban growth can be constrained by a range of factors including differential patterns of land ownership and physical barriers such as coastlines (e.g. Taubenböck, Wegmann, Roth, Mehl, & Dech, 2009). In Dubai, the main driver for recent urban development has been a political strategy to diversify the basis of the economy via inward investment in real estate, in the face of diminishing oil reserves. This policy has resulted in a ten-fold increase in the population of Dubai since 1975 (Dubai Statistical Centre, 2011; National Bureau of Statistics, 2010) mainly due to the increase in expatriate workers with locals forming only 8.8% of the total population in 2010 (NBS, 2011). Moreover, in Dubai, urban growth has not been constrained by physical boundaries such as the desertified terrestrial environment or the Gulf coast, or by issues of land ownership. Hence, this makes

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Dubai an interesting and important site for investigating the characteristics of urban development under a unique combination of drivers and apparent lack of constraints.

Satellite remote sensing has been widely used in studies of urban growth and offers a cost effective and time saving alternative to other conventional methods such as surveying (Patino & Duque, 2013). Over the last 40 years there have been significant advances in sensor technologies as well as digital image processing methods and analytical tools. The spatial, spectral and temporal resolution and coverage of satellite imagery has improved considerably, however there are often operational trade-offs between these parameters which can limit the applicability of the data for studying urban growth. For example, Gamba, Dell'Acqua, Stasolla, Trianni, and Lisini (2011) discussed the limitations of using high spatial resolution images to monitor urban growth due to their relatively low spectral resolution and coverage, in addition to their high financial cost and lack of a sufficiently long archive of imagery. The timescale over which urban growth has been investigated using remotely sensed imagery also varies considerably between studies; some researchers study urban growth over short time periods, for example, Moeller and Blaschke (2006) tested the feasibility of using Quickbird imagery to monitor Phoenix, USA from 2003 to 2005, while Rajendran, Arumugam, and Chandras (2002) used IRS-1A & 1C imagery in combination with old aerial photographs and topographic maps to study urban growth in Tiruchirapalli, India between 1928 and 1998. However, the most appropriate timescale is likely to be determined by achieving a balance between the known period and pace of urban development in an area and the availability of remotely sensed data of suitable temporal and spatial coverage and resolution for that area.

Data from the Landsat satellite series, considered medium-high spatial resolution, is available at no cost, with near-global coverage from 1972 to the present date. The higher spatial and spectral resolutions of the later Landsat TM and ETM+ sensors make them very useful for detecting urban areas and other forms of land cover. The earlier Landsat MSS sensor has lower spatial and spectral resolutions, but is the only accessible source of imagery for the period 1972–1984. The three sensors combined provide the longest time series of images with a relatively short revisit time (nominally 16 days) over the period in which Dubai has grown most rapidly, and therefore represent a potentially valuable source of information for understanding the process of development in the emirate. Previous researchers using remotely sensed data to study urban growth in arid environments have faced considerable challenges in discriminating urban areas from sand using multispectral imagery and a range of different techniques have been proposed. For example, Stewart, Yin, Bullard, and MacLachlan (2004) used an automated relative reflectance enhancement technique to aid discrimination, while Yagoub (2004) and Yin et al. (2005) used manual classification, but no universal solution has emerged. Hence, an appropriate method needs to be applied in order to achieve adequate levels of discrimination for Dubai using the Landsat data.

There has been a long-standing interest in the study of urban form and the analysis of urban growth in relation to demography and economy. Early urban growth theories included the Concentric Zone Theory (Burgess, 1924), the Sector Theory (Hoyt, 1939), the Multiple Nuclei Theory (Harris & Ullman, 1945) and the Wave Theory Analog Approach (Boyce, 1966). Increased computing power enabled the development of urban growth simulation models such as SLEUTH (Clarke, Hoppen, & Gaydos, 1997) to account for the key drivers of urbanization. More recently, empirically based models of growth have been developed as a result of advances in monitoring capabilities offered by remote sensing and analytical tools to quantify urban development (Dietzel, Herold, Hemphill, & Clarke, 2005; Dietzel, Oguz, Hemphill, Clarke, & Gazulis, 2005). In particular, there has been a growing interest in the use of landscape metrics to study urban structures and patterns of urban evolution (Aguilera, Valenzuela, & Leitão, 2011; Araya & Cabral, 2010; Taubenböck et al., 2009; Wu, Jenerette, Buyantuyev, & Redman, 2011). These metrics have been developed to analyse spatial configuration and pattern within landscapes in addition to the dynamics of landscape structure and heterogeneity (e.g., Alberti, 2008; Leitão, Miller, Ahern, & McGarigal, 2006; Yeh & Huang, 2009). In the context of the present study, landscape metrics provide a means of quantifying specific spatial characteristics of landscape patches, classes of patches of particular land cover types, or entire landscape mosaics and therefore have value in helping to understand the process of urban development at a range of scales.

The outputs from remotely sensed mapping exercises have been analysed using landscape metrics for a number of cities in order to inform models of urban growth (Dietzel, Herold et al., 2005; Dietzel, Oguz et al., 2005; Martellozzo & Clarke, 2011). These studies suggest that cities are developed through harmonic oscillation of two phases, diffusion and coalescence, with each phase consisting of multiple waves over different time periods. Dietzel, Ougz et al. (2005) indicate that this harmonic behaviour can be reflected by landscape metrics such as number of patches and Euclidian nearest neighbour distance for urban patches, but other metrics may not exhibit any harmonic behaviour. The oscillation of phases has been measured over different periods of time, such as the 11 oscillations over a 100 year period evidenced in Central Valley cities of California (Dietzel, Herold et al., 2005) or the 3 oscillations over 28 years found in Houston (Dietzel, Ougz et al., 2005). Given the distinctive drivers and styles of development found in Dubai, this city provides us with an interesting opportunity to examine the extent to which these existing models of urban growth are applicable in a rapidly developing coastal landscape that is typical of a number of cities that are emerging in the Middle East.

The objectives of this study are firstly to quantify land cover change in Dubai by conducting a spatiotemporal analysis of remotely sensed data and relate this to the economic, population and political drivers; secondly, to quantify changes in the spatial structure of the emirate through the use of landscape metrics; finally, to evaluate the extent to which the process of urban growth in Dubai conforms with the diffusion-coalescence theory (Dietzel, Herold et al., 2005; Dietzel, Oguz et al., 2005).

2. Materials and methods

2.1. Study area

Dubai is one of seven emirates forming the United Arab Emirates, being the second largest after Abu Dhabi in terms of population and area (Fig. 1). The total area of the emirate before the development of the islands was 3885 km^2 excluding Hatta which is an exclave city that has no boundary with Dubai Emirate (Department of Finance., 2009). Dubai Creek runs south from the Arabian Gulf for 13 km, dividing the city into Deira to the east and Bur Dubai to the west. Dubai is considered as hyperarid with an annual average rainfall of approximately 8 mm falling mostly in winter and late autumn (Dubai Airport, 2010).

Some historians date the origins of Dubai to 1833 when around 800 people settled in the creek area (Pacione, 2005). In this early period the economy was heavily reliant upon fishing and pearling, and Dubai was the transit point for overland trading convoys traveling from Iraq to the Sultanate of Oman and a strategic sea port for trading ships travelling between Asia, Africa and the Gulf region. Population growth accelerated in the 1970s after the discovery of large oil reserves in the emirate which attracted a large labour force, primarily from overseas countries. The Dubai government used the oil revenue to develop infrastructure and industrial