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Monitoring two decades of urbanization in the Poyang Lake area, China through spectral unmixing

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ABSTRACT

There is an increasing need to understand the dynamics in urbanization not only temporally but also spatially for the improvement of urban environments. In spite of an enormous number of previous studies in urban remote sensing applications, only a few studies have been conducted on the techniques in the quantification, qualification, and visualization of the changes in time-series urban land cover fractions (LCFs) derived through spectral unmixing. To examine the urbanization process in four major cities around the Poyang Lake area in Jiangxi Province, China – Nanchang, Jingdezhen, Yingtan, and Poyang – using a time-series Landsat-5 TM dataset in 1987, 1993, 1999, 2004, and 2009, we investigated: (1) the approach to the derivation of LCFs in urban areas using multi-temporal remotely-sensed data set; and (2) the approach to the summarization and cartographic manipulation of the changes in time-series LCFs. To account for the complex spectral confusion among different land cover materials in built-up areas, the Multiple Endmember Spectral Mixture Analysis (MESMA) was used for unmixing the pixels. The Land Cover Change Intensity (LCCI) was proposed to derive the average daily change rate in terms of the area within a pixel for the land cover classes of green vegetation, non-photosynthetic vegetation and soil, and built-up areas between two consecutive TM observation dates. The dominant LCCI (DLCCI) was proposed to determine in which period the urban areas were developed most rapidly and how intense the urbanization process was in each pixel of the time-series LCCI maps. Our results showed that MESMA could accurately model the pixels in urban areas with complex spectral confusion of different land cover materials. The comparison of derived land cover fractions with socioeconomic statistics disclosed the strong positive correlation between built-up fractions and urban population as well as gross GDP and GDPs in secondary and tertiary industries. LCCI and DLCCI revealed two mechanisms of urbanization, which are new land developments and redevelopments of built-up areas. Consequently, we found that the four cities around the Poyang Lake were urbanized through different mechanisms.

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1. Introduction

Urbanization has taken place at an unprecedented pace since the last century. Over 50% of the people in the world live in urban areas today (United Nations, 2009). The world urban population is expected to increase from 3.4 billion in 2009 to 6.3 billion in 2050. The United Nations anticipates that this global population growth will be concentrated in urban areas of developing countries through rural–urban migration. By the middle of the 21st century, more than half of the urban population of the world will be concentrated in Asian countries (Montgomery, 2008). In particular, the urbanization rate in China, which had an urban population of 620 million in 2009, ranks the highest among all Asian countries (4% average annual rate between 1975 and 2009), although the rate varies from city to city. This accelerated urbanization leads to the huge growth of population and economy as well as the severe deterioration of the environment, such as air and water pollution and problems with waste disposal (Weng & Quattrochi, 2007). In addition, urban areas are developed through the alteration of other land types including forests, vegetated areas, bare soils, and agricultural fields. As global urbanization progresses aggressively, there is an increasing need to understand its dynamics not only temporally but also spatially for the improvement of urban environments.

Satellite remote sensing has provided an efficient way to monitor and qualify urban environments by taking advantage of its wide area coverage and regular orbiting period. Moderate resolution optical remotely sensed data have been the preferred images used in previous studies to monitor urban land cover using traditional hard-labeled land cover classification algorithms, as in other applied fields of

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research (Treitz et al., 1992). However, this common approach has proven ineffective in urban environments, due to the unrealistic assumption of single land cover class in an image pixel with moderate resolution (Wu, 2004). One study evaluates the capability of satellite-borne hyper-spectral sensor on mapping urban environment, particularly the potential of mapping urban impervious surfaces (Xu & Gong, 2007). Land surface elements with different spectral characteristics, such as buildings, roads, vegetation, soil, and water, create a complex, spectrally mixed pixel when they are observed simultaneously within the instantaneous field of view (IFOV) of a sensor (Weng, 2001). A variety of approaches have been developed to break down mixed pixels to sub-pixel components of land covers in urban environments. Among them, spectral unmixing, or spectral mixture analysis (SMA), has widely been utilized to derive fractional contribution of representative urban land covers because it is simple to use and can derive physically interpretable information at sub-pixel level (Lu & Weng, 2006; Small, 2001; Small, 2002).

Although spectral unmixing is a popular method to understand urban land cover composition, only a few multi-temporal studies have utilized this technique for the monitoring of urban land cover changes (Rashed et al., 2005; Ward et al., 2000; Yuan & Bauer, 2007). Therefore, there is no well-documented approach in the quantification, qualification, and visualization of the changes of land cover fractions (LCFs). This research examines the urbanization process in a previously less developed urban area, the Poyang Lake area in China, using time-series moderate resolution remotely sensed data through the analysis of land cover fractional changes derived by spectral unmixing. More specifically, through the monitoring of the urbanization process in four cities near the Poyang Lake, we investigate: (1) an approach to extracting LCFs in urban areas using multi-temporal remotely-sensed data set; and (2) an approach to summarizing and mapping the changes in time-series LCFs.

2. Background

2.1. Urbanization in the Poyang Lake area, China

The Poyang Lake area (116° 13′ E, 29° 9′ N) is located in the northern part of Jiangxi province in China shown in Fig. 1. The economy of Jiangxi is below the national average level. For example, per capita gross domestic product (GDP) in Jiangxi (RMB 14,781) was much lower than the national per capita GDP (RMB 22,698) in 2008 (National Bureau of Statistics, China, 2009; Statistical Bureau, Jiangxi Provincial Government & Survey Office, National Bureau of Statistics in Jiangxi Province, 2009). This statistic is also an indication of its far slower pace of urbanization than that of other areas in China. Nonetheless, since the enforcement of the provincial strategy of bolstering the competitiveness of core industries in the Poyang Lake area in 2003, the population in Jiangxi has increased in a few large cities such as Nanchang, Jiujiang, Jingdezhen, and Yingtan (Commission for Development & Reform of Industry, Jiangxi Provincial Government, 2006). In particular, urban agglomeration has been apparent in the western and southern parts of this area since 2006 when the provincial economic development plan that aimed to optimize the industrial structure and accelerate urbanization was implemented (Commission for Development & Reform of Regional Economy, Jiangxi Provincial Government, 2006). In 2008, a population of 21.2 million in this area was made up of 48% population in the province, and about 38% of the population (8.0 million) was urban one (Statistical Bureau, Jiangxi Provincial Government & Survey Office, National Bureau of Statistics in Jiangxi Province, 2009). The wetland has been preserved at the expense of its slowed and staggered economy. Jiangxi's new economic and ecological development plan focuses on not only developing the economy, but also conserving the ecological environment (National Development & Reform Commission of China, 2009).

2.2. SMA and Multiple Endmember Spectral Mixture Analysis (MESMA)

SMA models mixed spectra in pixels of a remotely sensed image as a combination of pure spectra of distinct land surface components — endmembers (Adams et al., 1993). Endmembers can be collected through laboratory or field measurements, or from the images (Roberts et al., 1993). In linear SMA, a spectrum within the IFOV of a sensor (ρ'_λ) is determined by the sum of each endmember spectrum multiplied by its aerial coverage fraction and the residual error:

$$\rho'_\lambda = \sum_{i=1}^{N} f_i{}^*\rho_{i_\lambda} + \varepsilon_{\lambda,} \quad (1)$$

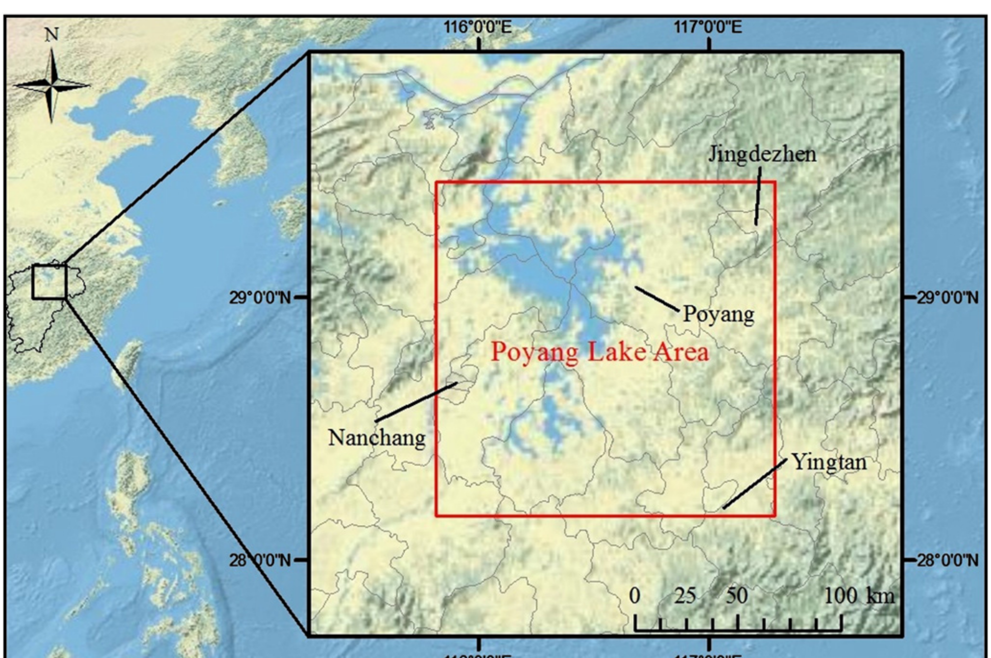

Fig. 1. Poyang Lake area, China.

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