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An evaluation of monthly impervious surface dynamics by fusing Landsat and MODIS time series in the Pearl River Delta, China, from 2000 to 2015

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ABSTRACT

Researchers have been attending increasingly to impervious surface dynamics to better understand the urbanization process and its impacts on urban environments. Previously, numerous studies have only estimated and mapped impervious surface dynamics at annual or decadal time scales. It is challenging to estimate impervious surface dynamics at a finer time scale, such as on a monthly scale, while using a single source of medium spatial resolution satellite imagery. However, urban infrastructure construction could cause changes in impervious surfaces in a short period of time. This paper aimed at developing a new methodology for evaluating monthly impervious surface dynamics by fusing Landsat and MODIS time series. The Pearl River Delta in China, is located in a humid subtropical region and was selected as the study area due to its dramatic urbanization in the past three decades. Available Landsat images with cloud cover < 90%, 7-Day MODIS NDVI 250 m smooth time series, and daily MODIS LST 1000 m time series from 2000 to 2015 were downloaded. These data were used to develop temporal features of land covers (i.e., monthly Landsat NDVI and LST time series) and to monitor impervious surface dynamics using semi-supervised time series fuzzy clustering method. The results showed the effectiveness of temporal features in differentiating land covers. Additionally, the average overall classification accuracy yielded reasonable accuracies (up to 89.36%). The proposed methodology has illustrated numerous, considerable advantages over previous methods. It has offered consistent maps of impervious surfaces on a monthly time scale as well as enhanced distinguishability of land covers with similar spectral characteristics. This study can be utilized to establish relationships between urban expansion, climate change, urban environment, population, and other socio-economic variables on a monthly basis. The study is also crucial for predicting the timing, duration, and density of ecological change for increased impervious surfaces.

1. Introduction

Impervious surfaces are a key variable for determining the degree of urbanization and environmental quality in cities. Numerous methods have been successfully employed for characterizing impervious surfaces at the local, regional, and continental scales, including spectral mixture analysis (Wu and Murray, 2003; Weng et al., 2008), regression (Yang et al., 2003; Yuan et al., 2008; Mohapatra and Wu, 2010), random forest (Zhang et al., 2014), and machine learning algorithms (Hu and Weng, 2009; Lu and Weng, 2009; Esch et al., 2009). Weng (2012) provided an overview of the methods for impervious surface estimation using remote sensing imagery at various spatial scales.

Researchers have been attending increasingly to impervious surface dynamics to better understand the urbanization process and its impacts on urban environments, rather than mapping impervious surfaces for a single date. For instance, Powell et al. (2008) quantified impervious surface change over 34 years (1972–2006) in the Snohomish Water Resource Inventory Area (WRIA), which illustrated the value of Landsat time series for monitoring impervious surface trends. Sexton et al. (2013) mapped annual dynamics of impervious surfaces from Landsat archive in Washington, D.C.–Baltimore, MD megalopolis from 1984 to 2010, which illustrated the potential of empirical retrieval of impervious coverage at spatial and temporal scales. Shao and Liu (2014) produced annual impervious surface fraction maps in the Yangtze River Delta, China, from 2000 to 2009, which demonstrated a method to monitor large-scale impervious surface dynamics.

However, previous methods focused mainly on impervious surface dynamics at annual or decadal time scales. Additionally, they were

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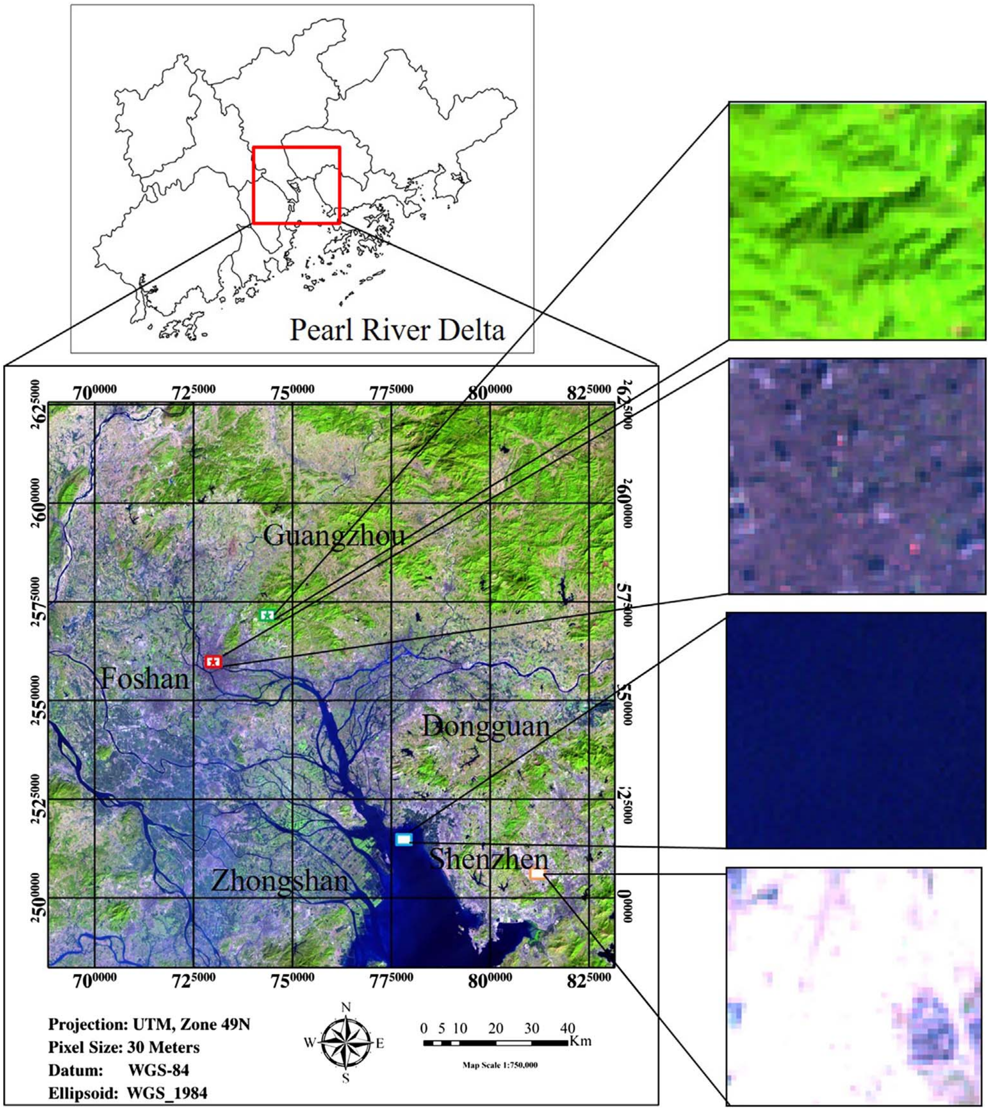

Fig. 1. Location and geographic extent of study area. The red rectangle stands for dark impervious surfaces; the orange rectangle bright impervious surfaces; the green rectangle pervious surface area; and the light blue rectangle water bodies. The red star is a representative impervious surface pixel; and the green star a representative pervious surface pixel. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

more concerned on increasing mapping accuracy of impervious surfaces for each date. Although these methods used multi-temporal or time series imagery, they mainly utilized spectral characteristics of land covers from single date image to differentiate land covers. Other methodologies utilized both spectral and spatial characteristics of land covers to map impervious surface dynamics by integrating medium and high resolution imagery. Lu et al. (2011) integrated multi-temporal Landsat and QuickBird images to monitor impervious surface change in Lucas do Rio Verde County, Brazil, which showed the effectiveness in fixing mixed pixel problems in urban–rural frontiers. Gao et al. (2012) developed a time series of consistent impervious surface maps using medium-resolution satellite images in the Yangtze River Delta, China. Nevertheless, these methods did not address the temporal characteristics of land covers from multi-temporal or time series imagery. Temporal profiles provide useful information that can enhance the identification of vegetation phenology as well as the trends and timing of changes (Ratana et al., 2005; Lunetta et al., 2006; Ma et al., 2013). Therefore, this study intended to explore the usage of temporal characteristics of land covers for mapping impervious surface dynamics at a monthly time scale.

The key for extracting the temporal characteristics of land covers is to utilize the temporal resolution of satellite imagery. Lunetta et al. (2004) suggested that an increment in temporal data acquisition frequencies helped to reduce omission errors of changes; change events largely determined the nominal temporal frequency of remote sensing data acquisitions. Changes in impervious surfaces have no fixed dates, because the changes mainly result from urban expansion, social-economic development and planning. As a result, the impervious surfaces may change inter-yearly, seasonal, monthly, or more frequently. Thus, it is necessary to map impervious surface dynamics on a finer time scale. Additionally, high temporal resolution is helpful for discerning the spatiotemporal patterns of change and differentiating the temporal characteristics of land covers. Recently, some image fusion models have been proposed to increase temporal resolution of medium spatial resolution satellite data, such as STARFM (Gao et al., 2006), STAARCH (Hilker et al., 2009), ESTARFM (Zhu et al., 2010), SADFAT (Weng et al. 2014), and FSDAF (Zhu et al., 2016). This study applied FSDAF to fuse Landsat and MODIS data for improving temporal resolution of the time series.

This study aimed at developing a new methodology to map impervious surfaces on a monthly basis using Landsat time series. Available Landsat data are often irregularly acquired due to cloud contamination, weather conditions and sensor failure. This is especially true for tropical or subtropical humid regions, such as the Pearl River Delta (PRD), China. The PRD region, with a subtropical climate, annual mean temperature of 21–23 °C and annual precipitation of 1500–2500 mm, has a wet season from April to October. Thus, there is a great chance for obtaining numerous cloud-contaminated Landsat