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Detection of impervious surface change with multitemporal Landsat images in an urban–rural frontier

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ABSTRACT

Mapping and monitoring impervious surface dynamic change in a complex urban–rural frontier with medium or coarse spatial resolution images is a challenge due to the mixed pixel problem and the spectral confusion between impervious surfaces and other non-vegetation land covers. This research selected Lucas do Rio Verde County in Mato Grosso State, Brazil as a case study to improve impervious surface estimation performance by the integrated use of Landsat and QuickBird images and to monitor impervious surface change by analyzing the normalized multitemporal Landsat-derived fractional impervious surfaces. This research demonstrates the importance of two-step calibrations. The first step is to calibrate the Landsat-derived fraction impervious surface values through the established regression model based on the QuickBird-derived impervious surface image in 2008. The second step is to conduct the normalization between the calibrated 2008 impervious surface image with other dates of impervious surface images. This research indicates that the per-pixel based method overestimates the impervious surface area in the urban–rural frontier by 50%–60%. In order to accurately estimate impervious surface area, it is necessary to map the fractional impervious surface image and further calibrate the estimates with high spatial resolution images. Also normalization of the multitemporal fractional impervious surface images is needed to reduce the impacts from different environmental conditions, in order to effectively detect the impervious surface dynamic change in a complex urban–rural frontier. The procedure developed in this paper for mapping and monitoring impervious surface area is especially valuable in urban–rural frontiers where multitemporal Landsat images are difficult to be used for accurately extracting impervious surface features based on traditional per-pixel based classification methods as they cannot effectively handle the mixed pixel problem.

1. Introduction

Digital change detection in urban environments is a challenge due to the following factors: urban land use/cover changes usually account for a small proportion of the study area and are scattered in different locations; they are often confounded with other changes because of the complexity of impervious surfaces and similar spectral features between impervious surfaces and other non-vegetation land covers; a large number of mixed pixels often result in poor classification accuracy due to the heterogeneous nature of urban environments and the limitation of spatial resolution in the remotely sensed image. Although many change detection techniques, such as principal component analysis, image differencing, and post-classification comparison, can be applied for urban land use and cover change detection (Singh, 1989; Coppin and Bauer, 1996; Coppin et al., 2004; Lu et al., 2004; Kennedy et al., 2009), the detection results are often poor, especially in urban–rural frontiers. The majority of previous change detection techniques are based on the comparison of spectral responses or classified images at the per-pixel scale. However, per-pixel based methods are problematic in accurately mapping and monitoring urban land use/cover change if medium or coarse spatial resolution images are used (Seto and Liu, 2003; Lu and Weng, 2004). Recent research has indicated that the subpixel-based impervious surface data sets have the potential to detect urban expansion (Yang et al., 2003a; Xian and Crane, 2005; Xian, 2007; Xian et al., 2008).

Urban landscapes can be regarded as a complex combination of buildings, roads, grass, trees, soil, water, and so on. In coarse and medium spatial resolution images such as Landsat Thematic Mapper (TM), mixed pixels have been recognized as a problem in the effective use of remotely sensed data in land use/cover classification and change detection (Fisher, 1997; Cracknell, 1998; Lu and Weng, 2004). As shown in Fig. 1, mixed pixels are common in TM imagery, but this problem almost does not exist in the QuickBird image (0.6 m spatial resolution here). Building shapes,

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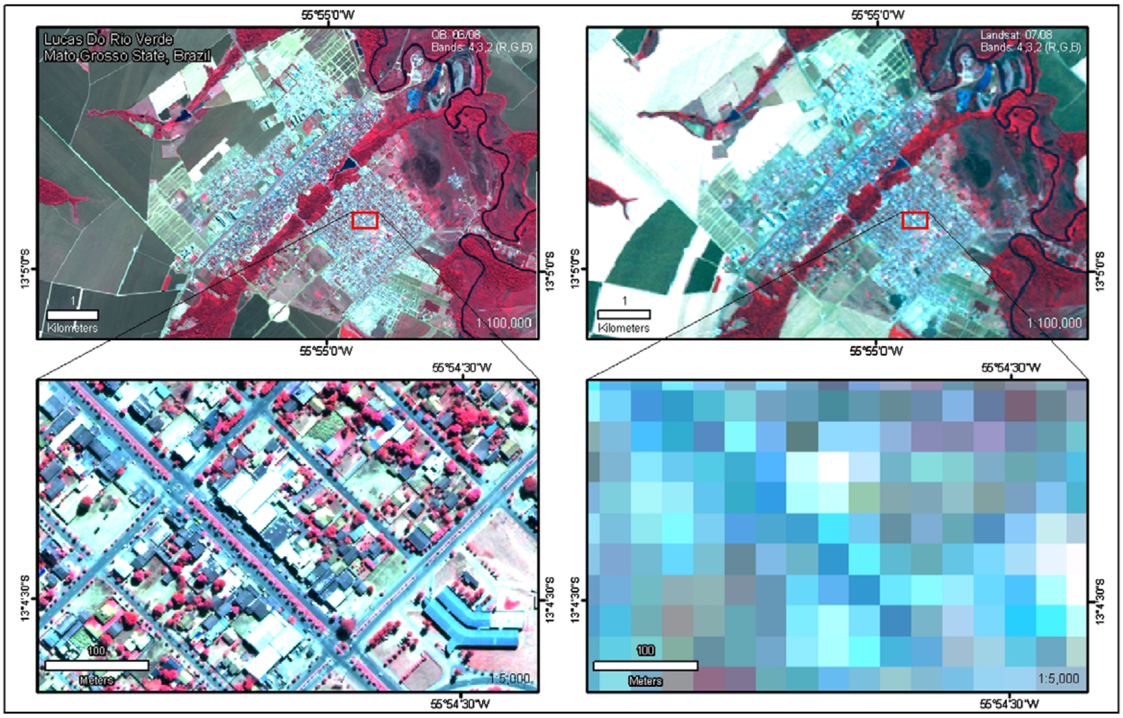

Fig. 1. A comparison of color composites between Landsat TM and QuickBird images (2008), illustrating the mixed pixel problem in relatively coarse spatial resolution images.

roads, and the boundaries between different land covers can be clearly identified on the QuickBird image, but these features cannot be detected in the Landsat TM color composite because of its relatively coarse spatial resolution (i.e., 30 m). This demonstrates the difficulty in urban land use/cover classification or change detection with Landsat TM images. If traditional per-pixel based methods such as the maximum likelihood classifier are used for urban land use/cover classification, urban areas may be significantly overestimated, but rural areas may be significantly underestimated (Lu and Weng, 2004). This situation worsens if multitemporal remote sensing data are used for urban land use/cover change detection, especially in the urban–rural frontiers. It is imperative to develop some new methods that can be used effectively to detect the dynamic change of urban land use/cover at the subpixel level with limited or no training samples for the historical remote sensing data.

Impervious surfaces are generally defined as any anthropogenic materials that water cannot infiltrate and are primarily associated with human activities and habitation through construction of transportation and buildings (Slonecker et al., 2001). Research on impervious surface extraction from remotely sensed data has attracted interest since the 1970s (Slonecker et al., 2001; Brabec et al., 2002; Weng, 2007). Many methods have been developed for mapping impervious surfaces with different spatial resolution images from high spatial resolution such as IKONOS and QuickBird (Mohapatra and Wu, 2008; Lu and Weng, 2009; Wu, 2009), medium spatial resolution such as Landsat TM and Terra ASTER (Deguchi and Sugio, 1994; Slonecker et al., 2001; Hodgson et al., 2003; Wu and Murray, 2003; Yang et al., 2003a,b; Dougherty et al., 2004; Jennings et al., 2004; Wu, 2004; Xian and Crane, 2005; Lu and Weng, 2006a,b; Powell et al., 2008; Wang et al., 2008; Weng et al., 2008; Esch et al., 2009; Hu and Weng, 2009; Weng et al., 2009) and coarse resolution such as DMSP-OLS (Elvidge et al., 2007; Sutton et al., 2009). The main methods include per-pixel image classification (Hodgson et al., 2003; Dougherty et al., 2004; Jennings et al., 2004), subpixel classification (Ji and Jensen, 1999; Phinn et al., 2002; Rashed et al., 2003), neural network (Mohapatra and Wu, 2008; Wang et al., 2008; Hu and Weng, 2009; Wu, 2009), regression tree model (Yang et al., 2003a,b; Xian and Crane, 2005; Xian, 2008; Xian et al., 2008; Yang et al., 2009), the combination of high-albedo and low-albedo fraction images (Wu and Murray, 2003; Wu, 2004; Lu and Weng, 2006a,b; Weng et al., 2009), and through the established relationship between impervious surfaces and vegetation cover (Gillies et al., 2003; Bauer et al., 2008). However, impervious surface areas are often overestimated or underestimated when medium spatial resolution images are used, depending on the relative proportion of impervious surfaces in a pixel (Wu and Murray, 2003; Lu and Weng, 2006a; Greenfield et al., 2009).

Ridd (1995) assumed that land-cover in urban environments is a linear combination of three components: vegetation, impervious surface, and soil (V–I–S). The V–I–S model provides a guideline for decomposing urban landscapes and a link for these components to remote-sensing spectral characteristics. Several studies have adopted this model as a basis for understanding the urban environment (Madhavan et al., 2001; Rashed et al., 2001; Phinn et al., 2002). Because of the complexity of impervious surfaces in remote sensing spectral signatures and the mixed pixel problem in medium or coarse spatial resolution images (see Fig. 1), subpixel based methods have obtained increasing attention in recent years (Wu and Murray, 2003; Wu, 2004; Lu and Weng, 2006a,b; Weng et al., 2009). These methods are especially valuable for accurately extracting impervious surfaces in the urban–rural landscapes.

Although previous research has explored methods for examining urban expansion based on impervious surface dynamic change (Yang et al., 2003a; Xian, 2007; Powell et al., 2008; Xian et al., 2008), detection of the impervious surface change in a complex urban–rural frontier with medium spatial resolution images remains a challenge. Because increase in impervious surface occurs mainly in the urban–rural frontiers over disperse locations, it is imperative to develop a processing method that can rapidly monitor the impervious surface change in a large area. Therefore, the objectives of this research are (1) to develop a new method to improve impervious surface estimation through the integrated use of Landsat TM