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Land cover and land use change analysis using multi-spatial resolution data and object-based image analysis

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ABSTRACT

Remote sensing data and techniques are reliable tools for monitoring and studying urban land cover and land use (LCLU) change. Fine spatial resolution (FRes) commercial satellite image in conjunction with geographic object-based image change analysis (GEOBICA) methods have been used to generate detailed and accurate urban LCLU maps. The integration of a backdating approach improves LCLU change classification results for the first date of a bi-temporal image sequences. Conversely, moderate spatial resolution satellite images such as those from Landsat sensors may not allow for detailed urban land use and land cover mapping. The objective of this study is to test a new bi-temporal change identification approach that integrates image classification of fine spatial resolution satellite imagery at time-2 and moderate spatial resolution satellite imagery (Landsat) at time-1, in a backdating and GEOBICA framework for mapping urban land use change. We compare the results from this approach to those of a GEOBICA approach based on fine spatial resolution imagery in both periods. The overall accuracy of the time-1 Landsat image classification is 0.82 and that of the fine spatial resolution image is 0.87. Moreover, the overall accuracy of the areal change data estimated from the pixel-wise spatial overlay of bi-temporal FRes LCLU maps is 0.80 while that from overlaying a time-2 FRes-generated map to that from a Landsat time-1 image is 0.81. The proposed method can be used in areas that lack FRes data due to limited coverage in the early 2000s.

1. Introduction

The exponential growth of the human population within the last two hundred years has caused important changes in the natural and built environments. The majority of the world's population now lives in urban centers, a shift from the past when people primarily lived in rural areas. Urban centers not only modify the natural environment that they are replacing, they also affect the well-being of the population living within them. Monitoring urban land cover and land use change is therefore important.

Remote sensing data of varying spatial resolutions and image change analysis techniques have been used to monitor changes in the urban environment. The spatial resolution of the dataset used in urban land cover and land use change (LCLUC) studies influences the level of detail of classification schemes and the accuracy of resulting maps. Momeni et al. (2016) compared the influence of spatial resolution, spectral band set and classification approach for mapping detailed urban land cover in Nottingham, UK, and found the spatial resolution to clearly be "the most influential factor when mapping complex urban environments." They concluded that image classifications with Landsat and similar moderate spatial resolution satellite systems were often limited to a general urban class, while very fine spatial resolution (VHR) imagery allowed for the discrimination of many urban land use sub-types. Other urban studies confirm their analysis. For example, Wang et al. (2012) used Landsat TM/ETM+ data to map the urban expansion in China between 1990 and 2010. Urban areas, bare soil, bodies of water, and vegetation were their main mapping categories. Odindi et al. (2012) used Landsat 5 TM data to monitor major land cover and land use changes in Port Elizabeth, South Africa between 1990 and 2000. They applied a post-classification comparison approach to change identification approach (Jensen, 2016) to monitor the built up, bare surface, green vegetation, beach or dune, and water classes. On the other hand, Ma et al. (2015) mapped eight land cover and land use classes based on Chinese advanced fine-spatial resolution satellite imagery and an object-oriented approach. Their classification scheme included the residential, commercial/Industrial, and transportation classes. Bouziani et al. (2010) developed an automated multispectral segmentation algorithm by integrating existing digital maps and

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spectral data. They also mapped detailed urban land use/land cover classes based on fine spatial IKONOS and QuickBird imagery.

Change detection can be performed through pixel- and object-based approaches. Several studies have demonstrated the advantages associated with geographic object-based image change analysis (GEOBICA) (Stow, 2009) compared to traditional per-pixel based change detection (Myint et al., 2011; Zhou et al., 2008). Geographic object-based image analysis (GEOBIA) (Hay and Castilla, 2008) approaches to image classification allow for multi-scale image analysis, more types of image features to be exploited for classification, and a great reduction in the occurrence of small, spurious pixel changes (Chen et al., 2012). Stow (2009) detailed the two general types of GEOBICA approaches to land cover and land use change mapping: 1) post-classification comparison where two separate GEOBIA land cover and land use maps are generated and spatially cross-tabulated, and 2) a multi-temporal layer stack approach where images for more than one date are segmented and resultant objects are classified as either land cover and land use transition classes or as no change. Multi-temporal time series of land cover maps can be generated by updating (projecting forward in time) and backdating (projecting backward in time) (Linke et al., 2009). Xian et al. (2009) developed a method to update the 2001 national land cover dataset (NLCD) to 2006. The method consists in identifying areas of land cover change occurring after 2001 and updating only those areas. For the areas that did not change, the original NLCD 2001 product is unchanged. In the updating/backdating approach, an existing map (often called the base map) is used as a starting point upon which subsequent classifications and change analyses are conducted. This approach has been shown to be both efficient and accurate (Linke et al., 2009; Xian et al., 2009). Yu et al. (2016) integrated the concept of updating/backdating with a GEOBICA approach to analyze land cover and land use change for the city of Beijing between 2001 and 2009. They found that the integration of the updating/backdating method to GEOBICA produced greater overall classification accuracies compared to an integration between the updating/backdating approach to a pixel-based analysis. They also found that the GEOBICA backdating approach greatly increased efficiency by focusing only on locations with changes. Toure et al. (2016) also integrated the backdating approach with GEOBICA and called it an object-based temporal inversion approach to urban land use change analysis. They also found that this approach improved the accuracy of time-1 LCLU maps, as well as that of the land use change classification products generated from fine spatial resolution satellite data for both dates of a bi-temporal image pair.

Past GEOBICA studies have involved datasets with similar spatial resolutions in time 1 and 2. Both the Yu et al. (2016) and Toure et al. (2016) studies that incorporated the backdating approach with GEOBICA, were based on datasets with similar spatial resolutions. Similarity includes near-anniversary dates of image capture, similar spatial, spectral, and radiometric resolutions, and approximately the same extents of coverage. However, this is not always achievable. No studies reported in the literature have used bi-temporal satellite images having very different spatial resolutions with a GEOBICA approach to land cover and land use change analysis. One reason is the unavailability of newer generation fine spatial resolution satellite imagery for historical dates. For example, fine spatial resolution imagery such as QuickBird or IKONOS became commercially available only in the late 1990s and early 2000s. Therefore, it is not possible to use them in change analyses that involve a date prior to 1999. Moreover, tropical regions of the world are affected with persistent cloud cover throughout most of the year, which makes it difficult to capture cloud-free and fine quality satellite imagery. Finally, commercial satellite coverage is partially driven by market potential; developing countries such as Ghana, the country within which our study area is located, may not have been considered a high value market such that tasking and capturing imagery for such countries occurred less frequently at the start of the commercial satellite era (c.2000).

Updating (projecting forward in time) and backdating (projecting backward in time) require a very accurate base map that provides partial basis for generating the land cover and land use map representing the other point in time. For example, the National Land Cover Database (NLCD) 2001 base map used to create the NLCD 2006 through the updating process is based primarily on a decision-tree classification of c.2001 Landsat satellite data and is comprised of three elements: land cover, percent developed impervious surface and percent tree canopy density. It does not contain a detailed urban land use classification scheme. Obtaining land use classes more specific than developed impervious will require dataset that have finer spatial resolutions than Landsat, and such fine spatial resolution images are more available after 2000. Backdating would be more appropriate in change identification studies that have finer spatial resolution data for the later period.

The objective of this paper is to test the accuracy of performing land cover and land use change analysis with a fine spatial resolution imagery for the second period and moderate resolution (Landsat 7 ETM+) imagery for the first period using an integrated backdating and GEOBICA approach. Specifically, the research questions are:

1. What is the utility of a post-classification change identification approach that is based on an initial object-based classification of a fine spatial resolution time-2 image, which is used to constrain the segmentation and subsequent classification of a time-1 moderate spatial resolution image?; and
2. Given the classes of interest (residential, non-residential, and non-built) for our broader study of drivers and impacts of land cover and land use change in major urban areas of Ghana, how accurately can land use be mapped based on Landsat ETM+ moderate spatial resolution satellite imagery?

2. Methodology

2.1. Study area and data

The study area is located in the Greater Accra region in southern Ghana (Fig. 1). The 545-km^2 study area consists of the entire Accra Metropolitan Area (AMA) and parts of seven other census districts: GA West, Ga East, Ga South, Ledzokuku/KROWOR, Adenta, Tema, and Ashaiman. Accra, the capital city of Ghana has experienced substantial population growth and built-up land since the country's independence in 1957. The population of Ghana grew from 5 million in 1950 to 25 million in 2010 (Ghana Statistical Services, 2012). Most of the population growth occurred in urban centers due to natural growth and internal migration. Only 15% of the population lived in urban areas in 1950 compared to 52% in 2010. The total urban area of Accra and its surrounding suburbs, regardless of the administrative boundaries, covered 216 km^2 in 1985, 276 km^2 in 1991, and 555 km^2 in 2002 (Møller-Jensen et al., 2005). The climate of the study area is tropical wet and dry and varies along an aridity gradient from the wetter coastal areas to drier parts inland. The prevalence of persistent cloud cover throughout the year as well as the harmattan, a dry, dust-laden wind in November–March, limits the availability of clear images. The equatorial vegetation that once covered the study area has been replaced by habitation, secondary forests, agricultural development and shrub thicket (Stow et al., 2016).

The study period for this research is the decade between 2000 and 2010. The period was selected as to coincide with the Ghanaian population and housing census, and to correspond with the availability of fine spatial resolution commercial satellite imagery for some portions of the study area.

Information about the data used in the study is listed in Table 1. Five and eight fine spatial resolution commercial satellite images were selected for the time period c.2000 and c.2010 respectively. These image data were made available to us at no cost through a NASA and National Geospatial Intelligence Agency (NGA) agreement. It was