International Journal of Applied Earth Observation and Geoinformation 47 (2016) 153–162

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Multiscale quantification of urban composition from EO-1/Hyperion data using object-based spectral unmixing

Caiyun Zhang*

Department of Geosciences, Florida Atlantic University, 777 Glades Road, Boca Raton, FL 33431, USA

ARTICLE INFO

Article history:
Received 19 November 2015
Received in revised form 13 January 2016
Accepted 15 January 2016
Available online 24 January 2016

Keywords:
Object-based MESMA
EO-1/Hyperion
Multiscale quantification
Urban composition

ABSTRACT

Quantification of the urban composition is important in urban planning and management. Previous research has primarily focused on unmixing medium-spatial resolution multispectral imagery using spectral mixture analysis (SMA) in order to estimate the abundance of urban components. For this study an object-based multiple endmember spectral mixture analysis (MESMA) approach was applied to unmix the 30-m Earth Observing-1 (EO-1)/Hyperion hyperspectral imagery. The abundance of two physical urban components (vegetation and impervious surface) was estimated and mapped at multiple scales and two defined geographic zones. The estimation results were validated by a reference dataset generated from fine spatial resolution aerial photography. The object-based MESMA approach was compared with its corresponding pixel-based one, and EO-1/Hyperion hyperspectral data was compared with the simulated EO-1/Advanced Land Imager (ALI) multispectral data in the unmixing modeling. The pros and cons of the object-based MESMA were evaluated. The result illustrates that the object-based MESMA is promising for unmixing the medium-spatial resolution hyperspectral imagery to quantify the urban composition, and it is an attractive alternative to the traditional pixel-based mixture analysis for various applications.

1. Introduction

Effective characterization and quantification of two biophysical components (i.e., vegetation and impervious surface) in an urban ecosystem is important for monitoring and modeling urbanization, urban sprawl, urban heat island effects, and urban environmental quality. A range of remote sensing methods have been developed to quantify these two compositions from medium-spatial resolution Landsat multispectral imagery (e.g., Small, 2001; Wu, 2004; Lu and Weng, 2004) and Earth Observing-1 (EO-1)/Hyperion hyperspectral imagery (e.g., Falcone and Gomez, 2005; Weng et al., 2008). Among these methods, the linear spectral mixture analysis (SMA) has been the most commonly used approach. SMA models each pixel as a linear sum of spectrally "pure" endmembers (Adams et al., 1986). Fraction maps demonstrating the abundance of each component within a pixel are produced. The value of SMA-derived sub-pixel fraction maps has been illustrated in various fields (Somers et al., 2011). However, SMA may fail to generate valuable results from medium-spatial resolution imagery in the heterogeneous urban environments. SMA requires the number of endmembers not exceed the number of spectral channels, thus it only allows a small number of endmembers to be considered in the model when multispectral imagery (e.g., Landsat data) is applied. In addition, SMA assumes that the set of endmembers present in a pixel is invariable, which again may cause considerable errors if the type and number of surface materials are highly variable over heterogeneous landscapes.

To address the problems in SMA, Roberts et al. (1998) introduced the multiple endmember spectral mixture analysis (MESMA) which allows the number and type of endmembers to vary for each pixel within an image. MESMA searches for the best-fit model for each input pixel based on a spectral library with many spectra to account for the spectral variability within a specific class. MESMA has proven invaluable in modeling urban land compositions from Landsat multispectral imagery (Rashed et al., 2003; Powell et al., 2007; Myint and Okin, 2009; Weng and Pu, 2013; Zhang et al., 2014), but its application in processing EO-1/Hyperion imagery to quantify urban components is sparse (Weng et al., 2008).

Applications of SMA or MESMA have concentrated on sub-pixel analysis by selecting endmembers, conducting mixture analysis, and producing fraction maps at the pixel level. In practice, urban planners and managers are less interested in a pixel than a composition or a configuration of many pixels which comprise a meaningful landscape within a scene. Information of a patch or a defined geo-

* Corresponding author.
E-mail address: czhang3@fau.edu

http://dx.doi.org/10.1016/j.jag.2016.01.002
0303-2434/

graphic zone is more useful. The object-based mixture analysis, i.e., selecting endmembers, conducting mixture analysis, and creating fraction maps at the object level, is more valuable in this context. The object-based image analysis (OBIA) offers a promising approach for such studies. OBIA has been well developed and widely applied in various fields, as reviewed by Blaschke (2010). Townshend et al. (2000) have pointed out that a significant problem usually ignored in the traditional pixel-based analysis is that a substantial proportion of the signal apparently coming from the land area represented by a pixel comes from the surrounding pixels. An alternative solution to this problem is to use contexture procedures in which observations from surrounding pixels are used to assist the analysis (Blaschke et al., 2004). OBIA analyzes objects instead of pixels which is an effective approach to reduce the effect from surrounding pixels by integrating neighborhood information. OBIA is also able to reduce the "salt-and-pepper" effect in mapping heterogeneous landscapes and enhance the analysis accuracy by smoothing the local noise and heterogeneity (Dronova, 2015). Another benefit of OBIA is that it allows for segmenting one image into objects/segments at multiple scales, providing a hierarchical set of scaled representations adaptable to required level of details for different applications. In contrast, the pixels are uni-scale and represent a fixed area on the ground with a non-hierarchical and single value. It is expected the object-based mixture analysis is a better solution to quantify the urban composition than the pixel-based one.

Previous research has focused on the application of medium-spatial resolution multispectral imagery to quantify urban compositions using the SMA (e.g., Small, 2001; Wu, 2004; Lu and Weng, 2004) or MESMA (Powell et al., 2007; Myint and Okin, 2009; Weng and Pu, 2013; Zhang et al., 2014). Application of the on-orbit spaceborne EO-1/Hyperion hyperspectral data is limited for the same purpose. Weng et al. (2008) evaluated the potential of EO-1/Hyperion imagery for extracting imperious surfaces using SMA, and compared the Hyperion with the EO-1/Advanced Land Imager (ALI) (multispectral sensor) in the model. They indicated that MESMA would be more effective than SMA in EO-1/Hyperion data analysis. But this has not been explored in the literature. Previous studies have also concentrated on the pixel-based mixture analysis. Exploration of object-based mixture analysis is limited. An integration of OBIA and MESMA techniques to process EO-1/Hyperion hyperspectral imagery for quantifying urban compositions is even scarcer. To this end, the main objective of this study is to model urban compositions at multiple scales from EO-1/Hyperion data by combining OBIA and MESMA techniques.

2. Study area and data

2.1. Study site

The city of Vero Beach located in Indian River County, Florida, was selected as the study area (Fig. 1). The study site with an approximate area of 25 km^2 includes the typical urban land-cover/land-use classes such as low density residential areas, high density residential areas, commercial areas, parks, cement roads, and tar roads. Agriculture, forests, and small wetlands are also present in the study site. Ridd (1995) conceptualized the urban fabric as a combination of three fundamental biophysical components (i.e., vegetation, impervious surface, and soil) existing in different percentages across the urban landscape, in addition to water. Most studies masked out water from further analysis. The selected study site is a city located along the east coast of central Florida. In most urban areas of Florida, bare soil is hardly seen while water is everywhere appearing as rivers, streams, canals, pools, lakes, and ponds. Many man-made freshwater lakes and ponds are parts of a storm water system to manage the runoff from rainfall and help prevent flooding. Thus a revised V-I-S model, V (vegetation)—I (impervious surface)—W (water) (V-I-W) model was used to in this study.

2.2. Data sources

Remote sensing data sources used in this study include hyperspectral imagery and aerial photography. The hyperspectral imagery was collected on 13 October 2012 by the EO-1/Hyperion Imaging Spectrometer. EO-1/Hyperion is the first spaceborne hyperspectral sensor acquiring imagery in 242 contiguous spectral bands (0.4–2.5 μm) at a spatial resolution of 30 m. The mission of EO-1/Hyperion is to evaluate in-orbit issues for imaging spectroscopy and to assess the capabilities of the spaceborne imaging spectrometer for earth science and observation (Folkman et al., 2001). The U.S. Geological Survey (USGS) has conducted the radiometric and systematic geometric corrections for the raw scenes. The preprocessed data are delivered to users as the Level 1 Gst products. The original scene was provided by USGS and subset to extract the study area. A 1-m aerial photography with four spectral channels (Red, Green, Blue, and Near Infrared) collected on 1 September 2013 by National Agriculture Imagery Program (NAIP) was used to validate the results from the EO-1/Hyperion. The aerial photography has been orthorectified by the USGS as Digital Orthophoto Quarter Quads (DOQQs) products. The accuracy and quality of DOQQs meet National Map Accuracy Standards (NMAS).

Two geographic zones, the land-use/land-cover and census block group, were also used in this study. Quantification of urban compositions for these two defined geographic regions was presented in this study. The digital land-use/land-cover geographic boundary is from the St. Johns River Water Management District. The data was created by the manual interpretation of 2009 color infrared aerial photography. A total of 353 regions were delineated including urban built-up, agriculture, forest, non-forest, wetlands, water, and transportation. The census block group boundary is from the U.S. Census Bureau which provides a range of cartographic boundary files known as the TIGER (Topologically Integrated Geographic Encoding and Referencing) products. The 2014 Census Block Group Boundary product was selected in this study. A total of 23 block groups were defined in the selected study area.

3. Methodology

3.1. Data preprocessing

Low-signal-noise ratio bands, uncalibrated bands, and severe stripping bands of the EO-1/Hyperion imagery were dropped, leading to 132 usable bands covering visible, near-infrared, and shortwave infrared for further analysis. After the noisy band elimination, an image-to-image registration was employed to georeference the hyperspectral data using the aerial photography. Radiometric calibration is frequently conducted for hyperspectral imagery if the spectral reflectance of the collected imagery needs to be quantitatively compared with in situ spectral reflectance data. It is not generally necessary to perform atmospheric correction in the analysis if a single scene is used. As long as the endmembers from the image to be classified/unmixed have the same relative scale (corrected or uncorrected), atmospheric correction has little effect on the analysis result (Jensen, 2014). For this study atmospheric correction of the EO-1/Hyperion imagery was unnecessary because firstly no comparison of spectral reflectance from EO-1/Hyperion data and in situ data was conducted; and secondly only one scene was used in the analysis. Hyperspectral data has a high dimensionality and contains a tremendous amount of redundant spectral information. The principle component analysis (PCA) was