International Journal of Applied Earth Observation and Geoinformation 50 (2016) 211–220

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

An efficient unsupervised index based approach for mapping urban vegetation from IKONOS imagery

Julius Y Anchang, Erick O. Ananga, Ruiliang Pu*

School of Geosciences, University of South Florida, 4202 East Fowler Ave., NES 107, Tampa, FL 33620, USA

ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form 8 March 2016
Accepted 2 April 2016
Available online 9 April 2016

Keywords:
Unsupervised classification
Vegetation index
Jenks natural breaks
Hierarchical clustering
Support vector machine
IKONOS imagery

ABSTRACT

Despite the increased availability of high resolution satellite image data, their operational use for mapping urban land cover in Sub-Saharan Africa continues to be limited by lack of computational resources and technical expertise. As such, there is need for simple and efficient image classification techniques. Using Bamenda in North West Cameroon as a test case, we investigated two completely unsupervised pixel based approaches to extract tree/shrub (TS) and ground vegetation (GV) cover from an IKONOS derived soil adjusted vegetation index. These included: (1) a simple Jenks Natural Breaks classification and (2) a two-step technique that combined the Jenks algorithm with agglomerative hierarchical clustering. Both techniques were compared with each other and with a non-linear support vector machine (SVM) for classification performance. While overall classification accuracy was generally high for all techniques (>90%), One-Way Analysis of Variance tests revealed the two step technique to outperform the simple Jenks classification in terms of predicting the GV class. It also outperformed the SVM in predicting the TS class. We conclude that the unsupervised methods are technically as good and practically superior for efficient urban vegetation mapping in budget and technically constrained regions such as Sub-Saharan Africa.

1. Introduction

Vegetation is an important component of the urban landscape, performing key functions such as mitigating the urban heat island (Susca et al., 2011; Yuan and Bauer, 2007), reducing carbon emissions (Nowak and Dwyer, 2007; Nowak and Crane, 2002; Seto et al., 2012), reducing air pollution (Nowak et al., 1998) and promoting general human health (Tzoulas et al., 2007). The quantification and characterization of urban vegetation thus remains a high priority for environmental research and policy.

Commercial satellite sensors such as IKONOS acquire high spatial resolution satellite (HSRS) imagery that provide land cover information with a level of spatial detail comparable with more costly field or aerial surveys (Jensen and Cowen, 1999; Xie et al., 2008). The general consensus among image analysts is that object based image classification approaches are preferable to pixel based methods when mapping urban land cover from HSRS image data (Mathieu and Aryal, 2007; Myint et al., 2011; Pu et al., 2011; Puissant et al., 2014). However, object based methods are not easy to implement in practice. They rely heavily on the manual and mostly subjective determination of key parameters (Blaschke, 2010) and the additional non-spectral attributes (e.g. spatial, contextual) computed for image objects significantly increases the dimensionality of the feature space, making the entire classification process more difficult. This often necessitates additional dimensionality reduction and/or feature selection procedures (Huang et al., 2014; Pu et al., 2011; Puissant et al., 2014). On the other hand, pixel based classification techniques are simple and efficient, but yet pose significant problems when applied to HSRS imagery of urban areas. This is mostly due to the high level of within class heterogeneity and between class overlap in spectral attributes (Pu et al., 2011).

Within the complex urban scene, green vegetation is a relatively spectrally distinct and homogenous class, due to its unique interaction with the electromagnetic spectrum during photosynthesis (Xie et al., 2008; Zha et al., 2003). Thus compared to other cover types, it is easier to extract green vegetation even at pixel level using only spectral attributes. To facilitate this process, vegetation indices are often used to enhance information content of imagery. The most commonly used index is the Normalized Difference Vegetation Index (NDVI) (Rouse Jr. et al., 1974) which is a normalized ratio of near infrared and red spectral bands, and consists of a range of values such that vegetated pixels occupy the upper end of the

* Corresponding author.
E-mail address: rpu@usf.edu (R. Pu).

http://dx.doi.org/10.1016/j.jag.2016.04.001

range whereas non-vegetated pixels occupy the lower end of the range (Jensen, 2005).

Because of this predictable data structure, vegetation indices are both intuitive and efficient for deriving vegetation maps. On their own, they have been very effective for mapping at large geographic scales, for example using time series NDVI data to discriminate cover types based on phenological differences (Hansen et al., 2000; Defries and Townshend, 1994; Lloyd, 1990; Knight et al., 2006). At a more localized scale, however, the classification of a single vegetation index to derive land cover is more of a manual exercise involving trial and error or visualizing index statistics from reference areas. For example, to map vegetation cover change for Accra Ghana, image analysts subjectively determined an NDVI threshold value of 0.2 to separate vegetation from non-vegetated areas in single date Quickbird imagery (Stow et al., 2013). In another study to map urban trees species from IKONOS imagery of Tampa, Florida, Pu and Landry (2012) used a systematic trial and error approach to determine the best vegetation index threshold that separates vegetation and non vegetated areas. Starting with a histogram based approximation, they systematically altered threshold values at constant small intervals until they could determine the value that resulted in the best accuracy with respect to reference areas (Pu and Landry, 2012). Considering the limitations of single index classification techniques (manual, subjective and heavily reliant on user knowledge), the following questions are posed: (1) Can we accurately and efficiently map urban land cover by a completely unsupervised classification of a single vegetation index? (2) Can vegetation index classification be extended beyond the simple binary separation of vegetation and non-vegetation land cover?

Clustering algorithms such as K-means and Iterative Self Organizing Data Analysis (ISODATA) are unsupervised classifiers that have been successfully used for mapping urban land cover from multispectral remote sensing data (Cleve et al., 2008; Iverson and Cook, 2000; Thapa and Murayama, 2009). The Jenks Natural Breaks (NB) algorithm, is also a simple unsupervised classification technique that was originally created to aid cartographers in improving the statistical accuracy of chloropleth maps (Jenks, 1967; Jenks and Caspall, 1971). In principle, it is similar to the K-means algorithm: splitting data into statistically homogenous groups by iteratively minimizing intra-group variation and maximizing the inter group separation (De Smith et al., 2007). Just as with the K-means method, the Jenks NB algorithm requires the specification of a predefined number of classes to produce as output. However, unlike the K-means (and most other flat clustering methods), the Jenks NB algorithm is optimized specifically for use with 1-dimensional data (Dent et al., 1999). Instead of seed points, NB classification initializes its iterations by the creation of arbitrary class boundaries based on the number classes. This does not only affect the consistency of the classification outcome, but also, the natural structure of the data may not be consistent with the predefined number of groups (De Smith et al., 2007). Agglomerative Hierarchical clustering (AHC) (King, 1967) mitigates this problem by treating each starting data point as a separate cluster, and then proceeding with hierarchical pair wise merging of clusters based on a proximity measure (Jain et al., 1999). As such, AHC is a completely deterministic method that is more sensitive to, and utilizes, the full distribution of the data. However because of its high computational complexity, AHC is not efficient with large data sets (Murtagh, 1983).

Considering the strengths and limitations highlighted in the above techniques (Jenks NB and AHC), this study was designed with an overall goal to investigate the possibility of a completely unsupervised classification of urban vegetation land cover (specifically, ground vegetation and tree/shrub cover) from a single vegetation index. This index is derived from IKONOS imagery acquired over the city of Bamenda in the North West Region of Cameroon. There were three sub-objectives: (1) to assess the ability of Jenks NB algorithm to accurately separate trees/shrubs and ground vegetation from non vegetated areas; (2) to determine whether classification accuracy was improved with a two step procedure that combined the Jenks NB algorithm with AHC; and (3) to compare the performance of both unsupervised classification approaches (simple Jenks NB, two-step approach) with a non-linear support vector machine (SVM) classifier trained on the same data.

In Sub-Saharan Africa, rapid urbanization is an ongoing process, causing significant land use/cover changes that need to be adequately monitored. Although HSRS imagery is more available and affordable for this region today than before, expertise in image processing and analysis as well as accompanying computational resources (hardware and software) is limited. This has in turn limited the large scale operational use of remote sensing data by relevant agencies such as the State, local government and non-governmental organizations. Thus the unsupervised approaches proposed and investigated in this study are context appropriate in the sense that they are completely data driven and designed to balance performance with simplicity and high capacity for automation and replication. The rest of the paper is organized as follows: study area and data sets, methodology, results and interpretation, discussion, summary and conclusions.

2. Study area and data

2.1. Study area

The study area is the extent of the city of Bamenda, located approximately 6°N and 10°E (Figs. 1 and 2). It is the administrative capital of the North West Region of Cameroon, with a population of about 270,000[1] making it the third largest city in Cameroon after Douala and Yaoundé. The wider region originally contains Guinea Savanna shrub/grassland vegetation and montane forests which can still be found in the areas surrounding the city. However, very little of the native vegetation survives within the city itself. The current urban vegetation in Bamenda (based on observation during recent field visits) is dominated by native hardwood (e.g., *Terminalia*), non-native hardwoods (e.g., *Cupressus* and *Eucalyptus*), fruit trees (e.g., *Citrus*, *Mangifera, Psidium*, *Pyrus*) and ornamentals (such as *Salix*). In addition to woody tree/shrub vegetation, there is ground (herbaceous) vegetation which is largely made up of grass fields and urban farmland.

2.2. Data

The primary data used for this study was Digital Globe's IKONOS imagery acquired on 22 January, 2006, and covering the full extent of the city (Fig. 1C). It included four-band multispectral (MS) data: Blue (445–516 nm), Green (506–595 nm), red (632–698 nm) and near-infrared (757–853 nm). In addition to the multispectral data was one panchromatic (pan) band image (526–929 nm). The 4 band imagery had a 3.2 m spatial resolution while the pan image had a 0.8 m spatial resolution.

3. Methodology

Fig. 3 summarizes the methodology used for this study. The objective was to extract vegetation land cover by classifying a Soil Adjusted Vegetation Index (SAVI) calculated from bands 3 (red) and 4 (near infrared) of IKONOS MS image data of Bamenda. Using ENVI software (Exelis Visual Information Solutions, Boulder, Colorado), both radiometric and geometric pre-processing was done on the

[1] 2005 National Household Census of Cameroon.