Assessing the accuracy of satellite-derived land cover maps classified using a hybrid pixel-based and object-based image analysis technique

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Abstract: The objective of this study is to assess the accuracy of various satellite-derived land cover maps classified using a hybrid pixel-based and object-based image analysis technique. A 2006 QuickBird image covering a part of the eastern side of Tsukuba City, Japan, was used to derive the land cover maps. First, we classified the image using a pixel-based technique. Second, we generated five different sets of object-based segments. And third, we combined the pixel-based classified map and segmentation results. This integration created a hybrid pixel-based and object-based classification procedure. The individual accuracy of the five hybrid classified land cover maps and the pixel-based classified land cover map was assessed using a pixel-based approach. The segments used in the classified land cover map that achieved the highest accuracy based on the pixel-based accuracy assessment approach were further evaluated using a polygon-based accuracy assessment approach.

Keywords: Accuracy; Figure of merit; Image classification; Land cover; Segmentation

1. Introduction

Pixel-based image analysis has been, and still is, the basis for many successful applications in remote sensing like land use/land cover mapping (Blaschke, 2010). However, recent advances in remote sensing technology (e.g. the launch of high spatial resolution satellite sensors) seem to have exposed some limitations of pixel-based image analysis, for example the ‘salt and pepper effect’ and limited integration of expert knowledge and feature space optimization (Platt and Rapoza, 2008; Liu and Xia, 2010). These limitations motivated other studies to explore and focus on object-based image analysis. Gamanya et al. (2009) observed that object-based image analysis has been becoming more popular compared to traditional pixel-based analysis.

The main principle of object-based image analysis is based on the concept of image segmentation. Image segmentation is a process of dividing an image into relatively homogeneous and semantically significant groups of pixels (Blaschke, 2010; Liu and Xia, 2010), which provide the building blocks of object-based image analysis (Hay and Castilla, 2008).

However, while other studies have shown that object-based techniques produce more accurate land use/land cover classification results than the traditional pixel-based techniques (e.g. Platt and Rapoza, 2008; Myint et al., 2011), other studies have also shown that a hybrid pixel-based and object-based technique can outperform both individual techniques (e.g. Wang et al., 2004; Bhaskaran et al., 2010). Our goal is to contribute to this endeavor as we assess the accuracy of various satellite-derived land cover maps classified using a hybrid pixel-based and object-based technique.

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Specifically, our study aims to compare the individual classification accuracy of the pixel-based and hybrid techniques, and evaluate object-based segments using a polygon-based accuracy assessment approach.

2. Data and methods

A pan-sharpened multi-spectral QuickBird satellite image of the eastern side of Tsukuba City, Japan (Fig. 1a), with a spatial resolution of 0.60 m and radiometric resolution of 16 bit, was used in this study. This part of the city was selected because it represents a diverse landscape, providing the necessary challenges for the hybrid pixel-based and object-based land cover classification technique. For the purpose of demonstrating and evaluating the hybrid technique, a subset measuring 1.5 km × 1.5 km (Fig. 1b) was clipped out from the QuickBird image as part of the pre-processing procedure.

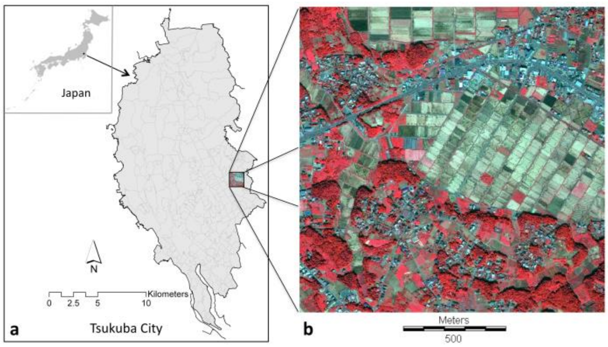

Fig. 1 (a) Tsukuba City, Japan; (b) A 1.5 km × 1.5 km subset of the QuickBird Image (October 9, 2006) (RGB = 432).

Firstly, a pixel-based image-classification technique (maximum likelihood supervised classification) was used to classify five land cover categories, namely built-up land, cropland, forest, other lands and shadow. Built-up land includes roofs of buildings and houses, roads, and all other impervious surfaces such as parking areas and tennis courts. Cropland includes paddy fields and other cultivated fields. Forest includes all tree stands; other lands include open areas such as grassland and lawns, while shadow includes all shadows of forest, trees, buildings, or any other surface features.

Secondly, image segmentation was carried out to produce five different sets of segments within an empirically determined optimum range of **S**imilarity **T**olerance or **T**hreshold (from ST 10 to ST 50) using the segmentation algorithm in IDRISI software. The ST parameter controls the generalization level: the larger the value, the lower the number of segments, which leads to more heterogeneous and generalized segmentation results. In addition to the ST parameter, a window width of '3' was used, while the four input bands were given equal relative weights. The weight mean factor and weight variance factor were both given a value of 0.5.

Finally, the pixel-based classified land cover map and results of the segmentation process were combined to create a hybrid classification procedure using the SEGCLASS module from the same software.

Accuracy assessment was performed for both the pixel-based and hybrid classification results using the traditional pixel-based approach. A total of 620 sample reference points were generated using stratified random sampling technique. These points were rigorously and carefully checked against the QuickBird image.

The segments used in the classified map that achieved the highest accuracy based on the pixel-based accuracy assessment approach (i.e. ST 30, see Section 3) were further evaluated using a polygon-based accuracy assessment approach, which determined the percentage overlap ($\%Overlap_i$) (Eq. 1) and figure of merit (FoM_i) (Eq. 2). The former provided a direct measure of how much of the reference objects or polygons was captured by the segments, while the latter measured the ratio of the overlap to the union of the overlap and segmentation errors (under-segmentation and over-segmentation) as a percentage. A total of 150 human-delineated polygons (30 per class) were used as reference.

$$\%\text{Overlap}_i = P_i \,/\, (P_i + U_i) \times 100 \qquad \text{(Eq. 1)}$$

$$\text{FoM}_i = P_i \,/\, (P_i + U_i + O_i) \times 100 \qquad \text{(Eq. 2)}$$

where P_i, U_i, and O_i are the overlapping, under-segmented, and over-segmented parts, respectively, based on the spatial comparison between sample segment $_i$ and its corresponding reference polygon, which are members of land cover class $_k$.

3. Results

The results revealed essential differences among the classified land cover maps (Figs. 2 and 3). The pixel-based classified map (Fig. 3a) showed the highest degree of 'salt and pepper' effect among the six classified land cover maps.

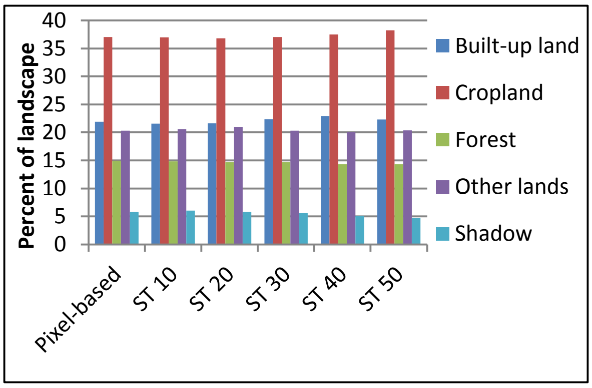

Fig. 2 Comparison of land cover statistics.

In terms of overall accuracy based on the pixel-based accuracy assessment approach, the land cover map produced by ST 30 had the highest accuracy (85.65%), followed by ST 20 (85.00%), ST 10 (84.03%), ST 40 (82.26%), and the pixel-based technique (80.00%), while ST 50 had the lowest accuracy (77.90%).

The results showed an overall average percentage overlap of 82.70% and an overall average FoM of 68.23% for the ST 30 land cover map.

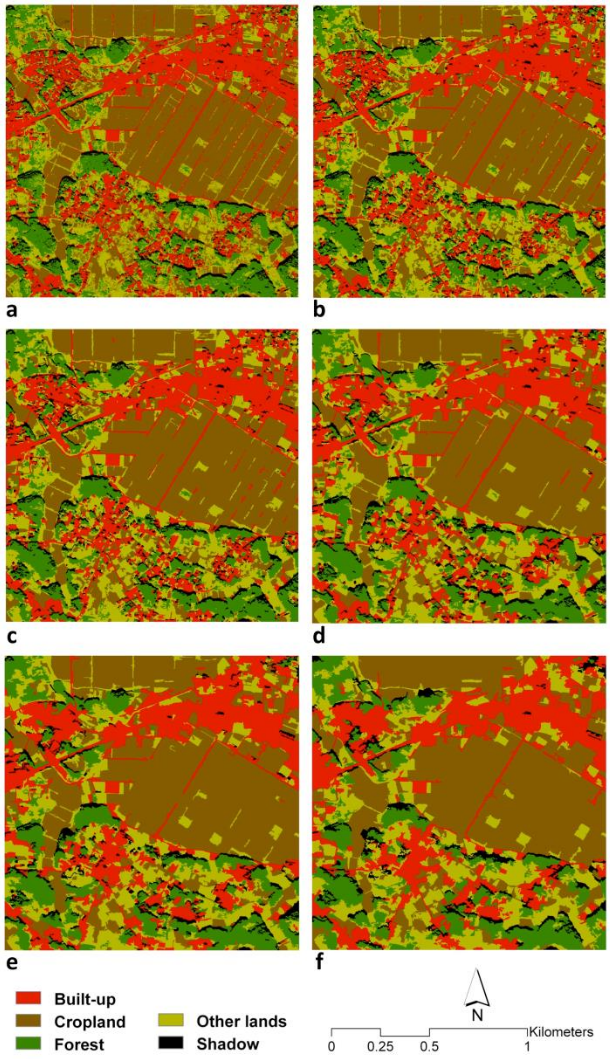

Fig. 3 Pixel-based and hybrid classified land cover maps. (a) Pixel-based; (b) ST 10; (c) ST 20; (d) ST 30; (e) ST 40; and (f) ST 50.

4. Discussion and conclusions

While pixel-based classification techniques work based on the spectral-radiometric information of individual pixels, an object-based technique has the capability to incorporate large-scale spatial, textural, and contextual information in the classification process.

The diverse landscape of the study area presented challenges and complexities in image analysis. Both the pixel-based and object-based classification techniques have their own strengths and weaknesses. The results, however, showed some indications that the hybrid technique was superior to the pixel-based technique. For example, four of the five hybrid classifications had much higher overall accuracies than the pixel-based classification. Thus, despite some limitations, e.g. poor capture of linear objects such as roads within cropland (Fig. 3), the hybrid technique showed some potential in improving pixel-based classifications, which could lead to more accurate satellite remote sensing-based land cover mapping.

The FoM, which was used as a measure of accuracy for a polygon-based accuracy assessment for object-based image analysis, gave additional information that both the pixel-based accuracy assessment approach and percentage overlap measure could not provide. The main findings suggest that while the hybrid technique was able to improve the pixel-based classified map, the sources of its classification inaccuracy came from both the pixel-based classifier and the object-based segmentation, including spectral confusion and the land cover class membership function used (majority rule within each segment). Both pixel-based and polygon-based accuracy assessment approaches are important in order for us to gain a comprehensive understanding of the sources of classification inaccuracies.

The high spatial resolution remote sensing satellite image used was helpful as it showed the features of the study area in detail and allowed visual interpretation and evaluation. However, the presence of shadow has affected the accuracy of both pixel-based and hybrid classification results to some extent. Apparently, shadow correction is an important topic for future research especially with the application of high spatial resolution satellite imageries.

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