EVALUATION OF WORLDVIEW-2 IMAGERY FOR URBAN LAND COVER MAPPING USING THE INTERIMAGE SYSTEM

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ABSTRACT:

Mapping of urban land cover using remote sensing technology has been widely explored, especially with the recent availability of high resolution images and object-based processing techniques. This study uses the InterIMAGE system and WorldView-2 orbital sensor imagery, two technologies which are new and still little explored in urban studies, to classify land cover in five test-sites near to the western section of Rodoanel Mário Covas, a ring-road that surrounds the metropolitan area of São Paulo, Brazil. The work hypothesis is: the spectral resolution increase of WorldView-2 imagery, compared to previous sensor systems, can improve the identification of urban targets, and consequently, improve the land cover classification. To evaluate the effects of the increase on spectral resolution of WorldView-2 system images, we simulated an image based on data from the QuickBird-2 sensor. Moreover, the framework for image classification InterIMAGE, which has been developed by PUC-RJ in cooperation with INPE, shows great potential for classifying complex urban areas. The proposed methodology is efficient to map the land cover in complex urban areas and the final classification of WorldView-2 images achieved an overall accuracy of 83% and a *Kappa* Accuracy Index of 0.81. The typical classification conflicts were solved, with a good identification of fifteen land cover classes. The results showed that the new spectral bands of the WorldView-2 were essential for discriminating some urban objects such as Ceramic Tile and Bare Soil, usually, difficult to be identified with other sensors of high spatial resolution, such as QuickBird-2.

1. INTRODUCTION

The acquisition of updated and detailed information about urban land cover is strategic for urban planning and management in present times, involving issues related to the recent massive urban sprawl and densification, climate change and the need for environmental protection. Mapping of urban land cover using remote sensing technology has been widely explored, especially with the recent availability of high resolution images and object-based analysis techniques (Blaschke, 2010).

Recently, the launch of WorldView-2 sensor, in October 2009, opened new perspectives for studying spectral properties of urban targets. This is the first high spatial resolution orbital sensor (0.46m in panchromatic band and 1.84m in multispectral bands) with eight multispectral bands ranging from Blue to Near Infra-Red parts of the electromagnetic spectrum. In comparison to other orbital sensors with sub-meter resolution, the availability of four more bands in the WorldView-2 sensor (WV-2) is expected to significantly increase the potential for urban land cover applications. Ribeiro (2010) and Ribeiro et al. (2011) have already showed its potential for such applications.

Therefore, this study aims to evaluate the performance of the WV-2 imagery for mapping urban land cover. For evaluation analysis, images acquired from QuickBird-2 sensor (QB-2) are also used in the experiments.

The experiments were developed in the InterIMAGE system, which is under development by PUC-RJ (Pontifical Catholic University - Rio de Janeiro) and INPE (Brazilian National Institute for Space Research), and it will be described in the next section.

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1.1 InterIMAGE System

InterIMAGE is an open source and free access framework for knowledge-based image classification, which provides high capacity for customization and extension tools. Costa et al. (2007; 2010), describe the InterIMAGE system in details. According to Costa et al. (2010), InterIMAGE is a multi-platform framework, implemented for LINUX and Windows operational systems. The System is coded in C++, using also the QT4 crossplatform application development framework (Summerfield, 2010), the Visualization Toolkit (VTK) class library (Schroeder et al., 2006) and Terralib (Camara et al., 2000), a GIS classes and functions library developed at INPE.

InterIMAGE provides support for the integration of image processing operators in the interpretation process and, as such operators are treated as external programs by its control mechanism, they can be coded in any computer language, and can even be proprietary programs (Costa et al, 2010). The Inter IMAGE framework offers, nonetheless, a suit of basic operators (http://www.dpi.inpe.br/terraaida), assembled with the classes and functions supplied by the TerraLib library (Câmara et al., 2000).

InterIMAGE's interpretation process is guided by a knowledge model, which embodies and explicitly represents prior knowledge about a particular geographic region and about the objects expected to be found in it. The knowledge model can correspond to the user's prior knowledge or the knowledge acquired by analyzing the input data (RS images or GIS layers) through the tools provided by the system (Costa et al, 2010). The classification strategy is based on a knowledge model structured as a semantic net defined by the user. The classification process has two steps: the Top-Down and the Bottom-Up (Costa et al., 2007).

In the Top-Down step, the system descends the semantic net triggering the so-called holistic operators. Holistic operators are image processing operators, external to the system's core, specialized in the detection of a certain class. For the detection of objects from the corresponding class, holistic operators usually perform three procedures: segmentation (or import GIS data), attribute extraction and classification. The geographic regions detected by a holistic operator inserted into a given node are transmitted as masks ("hypothesis") to its child nodes on the lower level of the semantic net, where its own holistic operators will work.

In the Bottom-Up step, the system ascends the semantic network solving spatial conflicts between hypotheses based on user-defined rules inserted in every node that is not a leaf node. Doing so, the system either partially or totally discards the hypotheses or turns them into instances (i.e. validates the hypotheses). The user-defined rules may involve additional logical selections. If after the discard of hypotheses by these additional logical selections spatial conflicts still remain, they are solved either by the supervised definition of priority for the classes or by the competition of membership values given by user-defined fuzzy membership functions.

The final instance network results from the Bottom-Up analysis: when bottom-up operators reach the top of the semantic network, labelled images are created for each different level of the semantic network.

2. METHODOLOGY

The methodological steps are summarized in the block diagram in Figure 1.

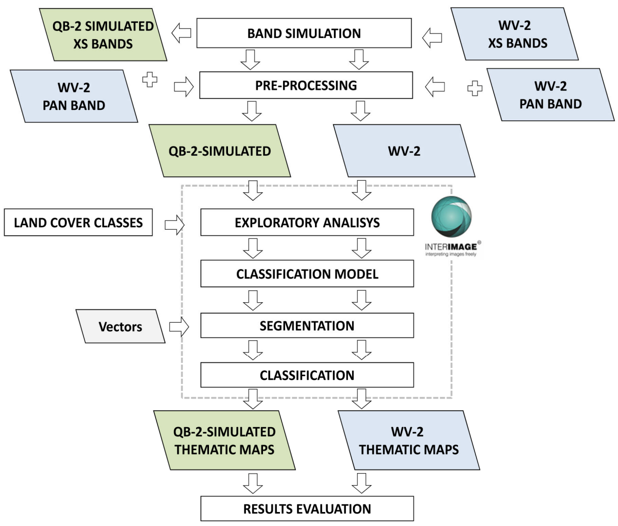

Figure 1. Methodological procedures for urban land cover mapping. "XS bands" stands for multispectral bands and "PAN band", for the panchromatic band.

2.1 Study Area

The study area is located along the western section of the Rodoanel Mário Covas, a ring-road that surrounds the metropolitan area of São Paulo, Brazil. As shown in Figure 2, five test sites (A, B, C, D and E) were defined. They address a wide range of urban targets, such as swimming pools, scrub and trees, different types of roofs, buildings with variable heights, warehouses, etc.. These urban objects are frequently spatially arranged in a dense and complex manner and can be found in different states of conservation. Moreover, despite having similar colorations, these objects have very different chemical compositions and physical properties. Furthermore, no geometrical and contextual patterns are constant in this urban area, which makes even a visual interpretation a difficult task.

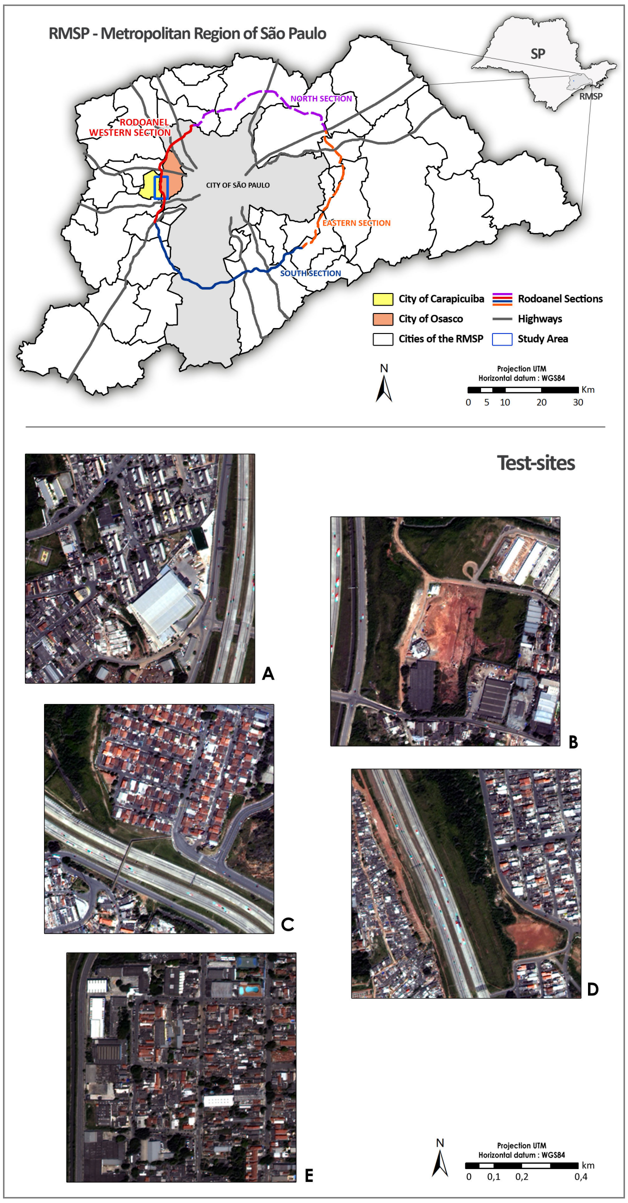

Figure 2. The study area location along the western section of Rodoanel Mário Covas, in the Metropolitan Region of São Paulo. The five test-sites are also shown above.

2.2 Image Simulation

The QB-2 spectral bands were simulated from WV-2 bands using their spectral responses. The data simulation process is an important processing step in this study because it allows obtaining QB-2-Simulated images with the same spatial resolution and imaging acquisition conditions as those of WV-2 sensor.

The procedure, based on Mascarenhas et al. (1991), uses the weighted sum of the WV-2 spectral responses, in which the weights define the contribution of each input band to generate an output spectral band. The new QB-2 simulated dataset has the same spatial resolution (2.0m) and imaging acquisition conditions as the multispectral WV-2 imagery.

2.3 Pre-processing

A fusion technique based on Principal Components was applied to process the WV-2 and QB-2 multispectral bands and the panchromatic WV-2 band to produce two hybrid images, so called QB-2-Simulated and WV-2, both with spatial resolution equal to 0.5 meter.

After fusion processing, the WV-2 and QB-2-Simulated images were orthorrectified by applying the 3D rational polynomial method. The values of RMSE (Root Mean Square Error) obtained were 1.15m and 1.07m, for the E and N planimetric components, respectively.

2.4 Land Cover Classification Analysis

Fifteen land cover classes were established, considering the possibility of their identification in the study area: Grass and Shrubs, Trees, Bare Soil, Ceramic Tile Roof, Metallic Roof, PVC Roof (PolyVinyl Chloride), Asphalt, Clear, Grey and Dark Concrete Material, Natural Stone, Swimming Pool, Stream and Shadow.

The task of mapping the land cover in the study area was performed using the software InterIMAGE v0.95 (InterIMAGE, 2010). Initially, the behavior of each land cover class was assessed through feature exploratory analysis. The segmentation, using TerraAIDA Baatz&Schäpe algorithm (Baatz and Shäpe, 2000) generated hypothesis clusters for each land cover class in the top-down step. The classification was carried out in the bottom-up steps, solving conflicts among the classes. Conflicts were solved by giving priority to classes whose attributes would distinguish them better with fewer omission and commission errors.

2.5 Classification Accuracy Evaluation

The classification accuracy was assessed through the confusion matrix, *Kappa* and conditional *Kappa* indices. From the confusion matrix, two descriptive measures were calculated: the user and producer overall accuracy (Cohen, 1960; Rosenfield and Fitzpatrick-Lins, 1986; Story and Congalton, 1986).

3. RESULTS

Ten thematic maps were produced by classifying QB-2-Simulated and WV-2 imagery for five test sites. The land cover thematic maps of one of the test sites are illustrated in Figure 3. Broadly speaking, we can observe a better distinction of urban land cover classes for WV-2 classification than for QB-2-Simulated classification.

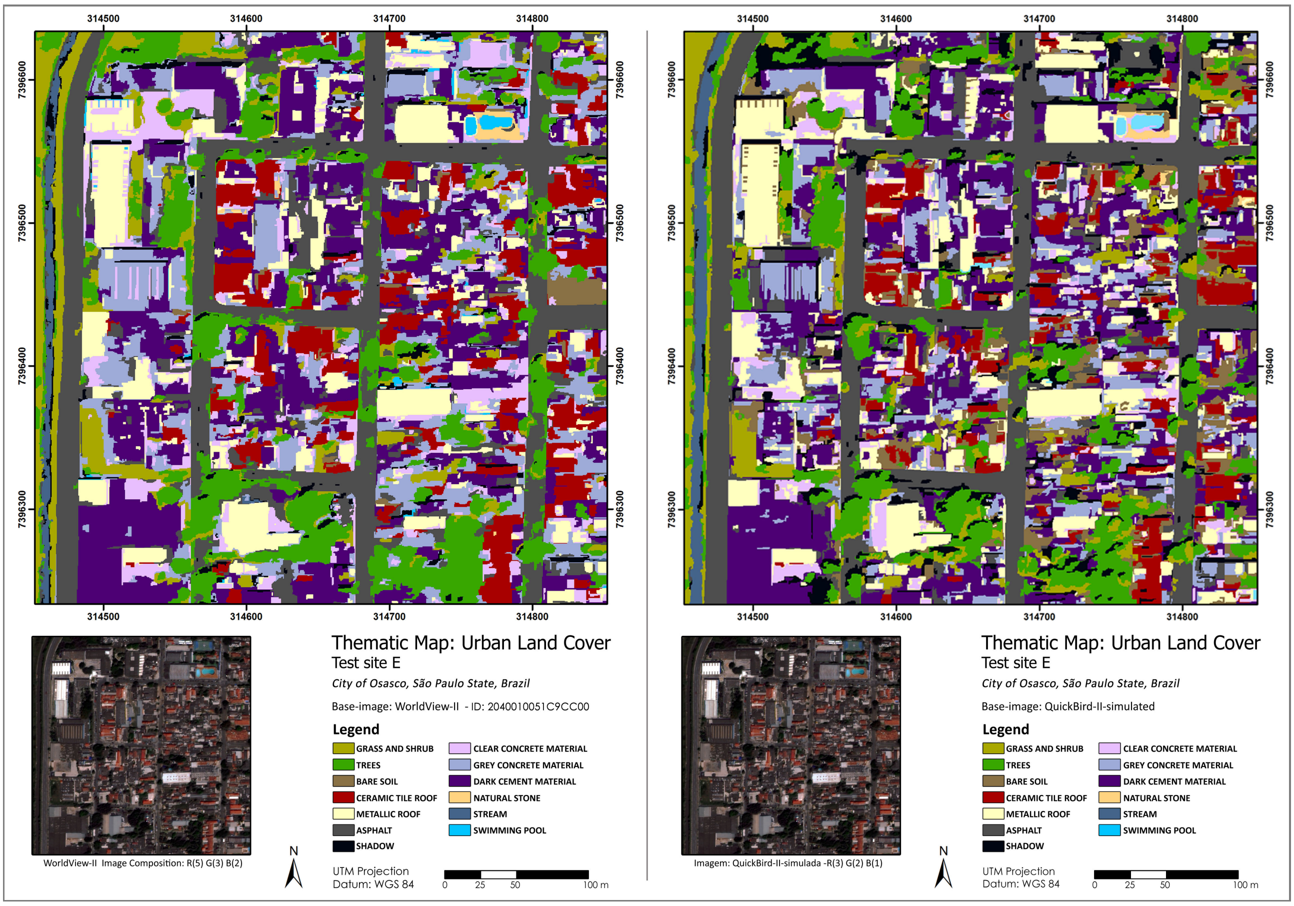

Figure 3. Thematic maps obtained from WV-2 (left) and QB-2-Simulated (right) images.

Statistical analysis indicated that thematic maps produced from WV-2 images are significantly different from those produced from QB-2-Simulated imagery. The overall accuracy and *Kappa* values for WV-2 thematic maps were higher than those obtained for QB-2-Simulated imagery for all test sites (Table 1).

Overall, the discrimination between all classes was better for WV-2 than for QB-2-Simulated images, which was evaluated through the conditional *Kappa* index and the user and producer accuracy. The graph shown in Figure 4 illustrates the values of conditional *Kappa* for each land cover class present in test-site E scene, obtained from the thematic maps produced from WV-2 and QB-2-Simulated images.

Test site	Image	Overall accuracy	*Kappa* Index	*Kappa* - Variance	*Z* Test
A	WV-2	0.84	0.81	0.000644	3.30
A	QB-2 - simul.	0.73	0.68	0.000900	
B	WV-2	0.88	0.85	0.000545	5.14
B	QB-2 - simul.	0.70	0.64	0.001080	
C	WV-2	0.90	0.89	0.000426	6.93
C	QB-2 - simul.	0.68	0.62	0.001007	
D	WV-2	0.88	0.86	0.000524	5.45
D	QB-2 - simul.	0.69	0.64	0.001006	
E	WV-2	0.84	0.82	0.000573	5.19
E	QB-2 - simul.	0.65	0.61	0.000962	

Table 1. Overall accuracy, *Kappa* index and variance of the *Kappa* index for the ten classifications.

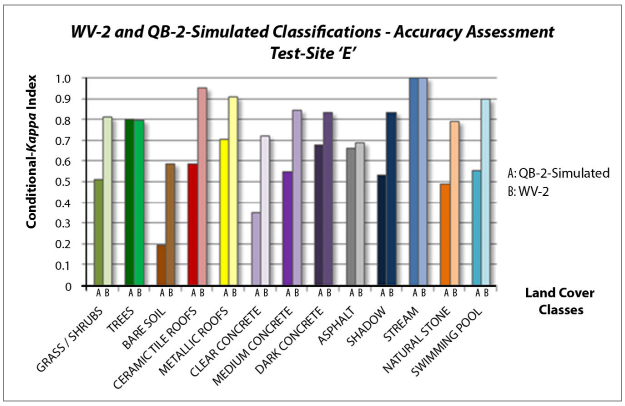

Figure 4. Conditional *Kappa* indices obtained for the land cover classes of test-site E.

In relation to the "red" objects, the crucial issue is the differentiation between Ceramic Tile Roofs and Bare Soil. Though these objects have very similar compositions, these targets are semantically different. Ceramic tiles represent buildings and bare soil indicates an unoccupied area and non-impervious surface. The distinction of these classes represents a difficulty faced by prior studies developed with the use of sensors with few and broad spectral bands, due to the ceramic tiles preserve the spectrum similar to its source material (e.g., Novak and Kux, 2010; Pinho et al., 2008, Thomas et al., 2003).

Generally, the distinction of the Bare Soil class, compared to ceramic roofs and thin or dry grass, is very difficult, since they have similar spectral responses. However, the use of additional spectral bands has improved the outcome of the classifications of ceramic tiles. The WV-2 images allowed the distinction of objects of Ceramic Tile class from those of Bare Soil class due to the use of attributes related to the Yellow, Red-Edge and NIR-2 bands. While the values of conditional *Kappa* index for the classifications of the QB-2-simulated images were ranging between 0.33 and 0.62, the ratings of the WV-2 images obtained values between 0.63 and 1.00 for this index.

4. CONCLUSION

Using two technologies that are new and still little explored in urban studies, this work aimed to explore the WorldView-2 sensor imagery and the free open-source software InterIMAGE for urban land cover classification, building a quantitative comparison of WorldView-2 imagery and QuickBird-2-simulated imagery regarding object-based urban land cover classification.

The evaluation analysis was carried out by comparing thematic maps generated from QB-2-Simulated and WV-2 imagery. The data simulation process is an important processing step in this study because allows obtaining QB-2-Simulated images with the same spatial resolution and imaging acquisition conditions as those of WV-2 sensor. The hypothesis that the enhanced spectral resolution images from WV-2, in relation to other images with high spatial resolution available, can improve the identification of urban targets, and consequently improve the classification of land cover, was considered feasible, considering the higher values of the accuracy indices obtained over the resulting thematic maps produced with WV-2 images.

Overall, WV-2 images got better classification performance than QB-2-Simulated imagery. The confusion between classes that commonly occur in the classifications of QB-2 imagery was reduced. Particularly, the use of Yellow and Red-Edge bands of WV-2 allowed better discrimination between Bare Soil and Ceramic Tile Roofs classes, which, according to the literature, do not have good separability on urban land cover classification using only satellite images of high spatial resolution. The results for these classes presented better performance in the classification of the WV-2 images, compared to results obtained from the QB-2-simulated imagery. Moreover, features related to Yellow band were present in the classification model to distinguish all land cover classes.

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