OBJECT-ORIENTED ANALYSIS OF HIGH-RESOLUTION SATELLITE IMAGES FOR INTRA-URBAN LAND COVER CLASSIFICATION: CASE STUDY IN SÃO JOSÉ DOS CAMPOS, SÃO PAULO STATE, BRAZIL

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ABSTRACT:

The detailed analysis of urban regions is among those areas which most benefited from the availability of high-resolution satellite data such as e.g. *IKONOS* and *QUICKBIRD*. These data offer as well high spatial, radiometric and temporal resolution, competing with aerial photographs for several applications. Merging these characteristics allows the detection of intra-urban targets and consequently proves to be suitable for mapping urban and intra-urban land cover using automatic classifiers. Taking into account the huge volume of data at each scene from these sensor systems (11 bits, 2048 gray levels) the conventional pixel-by-pixel classifiers, considering only spectral characteristics, show clear limitations for classification tasks. An alternative to this shortcoming is the incorporation of other types of attributes to the classification process, such as shape, size, color and contextual information. Being so, we used an object-oriented classifier from software package *eCognition* 4.0 which is an effective option, since it uses both topologic (neighborhood, context) and geometric information (shape and size). In this frame, an image classification experiment was conducted for test-site São José dos Campos, São Paulo State (Brazil), where a classification scheme was conceived and applied using both *IKONOS* and *QUICKBIRD* data. The classification results were compared and evaluated in order to assess which sensor allows best classification performance in such a highly complex and heterogeneous environment.

1. INTRODUCTION

With the advent of high-resolution satellites, new challenges did arise for the automatic classification of land use/land cover of intra-urban areas. The traditional pixel-by-pixel classifiers are quite limited for the classification of images from these sensor systems, which capture details of very heterogeneous urban scenes with a large internal class variation, such as e.g. classes of roofs which behave differently to the variations of incidence angle and to the orientation of its faces (Neubert & Meinel, 2005, Schiewe & Tufte, 2005). Furthermore these images present low spectral resolution (just bands blue, green, red and near infra-red) which makes it difficult to distinguish several urban targets presenting a similar behavior in the visible wavelength, such as streets paved with asphalt and roofs covered with dark asbestos plates. In this frame alternative classification methods must be explored which are not limited to spectral attributes. Among these methods we detach the object-oriented analysis, which permits the insertion of knowledge of the analyst as well as the parameters color, form, texture and context at the image classification.

In this work, which is part of a larger study done by Pinho (2005), it is assumed that the introduction of knowledge in the classification process would help to supplant the difficulties of information extraction from very high spatial resolution images. The objective of this study is the analysis of the quality of object-oriented classifications from an intra-urban land cover, using both IKONOS and QUICKBIRD data from the municipality of São José dos Campos, São Paulo State, Brazil. In order to overcome the above mentioned problem of pixel-by-pixel classifiers at high-resolution images, one alternative is the region-based classification (Blaschke & Strobl, 2001; Pinho & Kux, 2004; Pinho et al., 2005), where initially a segmentation is done that consists in the grouping of neighbor pixels in regions or segments, based on a similarity criterion like texture or digital number (Meinel et al., 2001). Afterwards the resulting regions were classified. This type of approach presented better results than the traditional pixel-by-pixel approach when it is applied to very high resolution images (Antunes 2003; Rego 2003; Rego & Koch 2003).

In order to perform the object-oriented image analysis some important premises must mentioned, namely:
1. The characterization of image objects cannot be limited only to spectral attributes, because frequently they are not able to delimit complex objects, such as e.g. the roof of a house with a large spectral variability within its borders. Therefore is also necessary to use other attributes such as: form, size, texture, standard, color and context. This means: to insert knowledge of the analyst in the image interpretation system.
2. The objects of interest to be extracted from a certain scene can be associated to different abstraction levels (i.e. different scales) and these levels must be represented in the analysis system.
3. The description of the space of attributes from a certain class can be inexact, which introduces uncertainties in the association of an object to a certain class. This uncertainty must be modeled, because it is part of the classification result (Benz et al. 2004).

The materialization of theses premises is given by multi-resolution segmentation procedures and class structuring in a hierarchical network. The multi-resolution segmentation is responsible for the generation of image objects at different scales of detail. In order to set up classes in a hierarchical net, the objects and its' relationships are modeled by classification rules. These classification rules can use fuzzy membership functions which model the incertitude associated to classes.

2. MATERIALS

The following materials were used for this study: 1. Two *Quickbird* scenes (Ortho-ready Standard) being one

panchromatic with 0,60 m spatial resolution and another multi-spectral with 2,40 m resolution at blue, green, red and infrared bands. The images dated from May 17th 2004, have an off-nadir incidence angle of 7,0º and a radiometric resolution of 16 bits, although the pixels are distributed along only 11 bits; 2. Two *Ikonos* scenes: one panchromatic with 1,0 m spatial resolution and another with 4,0 m resolution at blue, green, red and infrared bands. The images dated from March 13th 2001 have an off-nadir incidence angle of 4,85º and radiometric resolution of 11 bits.; 3. Databank "Cidade Viva" (PMSJC, 2003) from the Prefecture of São José dos Campos for the characterization of the area under study and extraction of digital bases of quarters and blocks used in the study.
For the object-oriented image analysis the *eCognition* 4.1 software package from DEFINIENS (2003) was used.

3. METHODS

The main working hypothesis of this study is that the introduction of knowledge in the classification process can help to overcome the difficulties at the extraction of information from images of very high spatial resolution, allowing the differentiation between urban targets. In order to test the validity of this hypothesis, we conducted a classification experiments in a complex intra-urban environment, test-site São José dos Campos, São Paulo State (Brazil), creating a classification scheme, which was applied to the entire area under study selected, using images of both sensor systems. The results of the two classifications were evaluated and compared, which sensor has a better performance in such a heterogeneous area.

3.1 Characterization of classes

The selection and characterization of classes of interest was done based on visual interpretation of the fused images, aiming to identify the main materials used for the pavement of streets, for the cover of constructions as well as vegetation types. This was done using interpretation keys elaborated, where elements such as color, size, form, localization and texture were analyzed.

3.2 Segmentation

During this phase the levels and segmentation strategy (bottom up or top-down) used were defined, as well as the tests with the parameters of scale, color and form, adequate for each level of the 4 segmentation levels created.
At each level the objects of interest were defined, which objectives should be attended, the files used for segmentation as well as the parameters (Color or Form) that were higher weighted for Segmentation (Table 1).

Referring to the parameter prioritized for segmentation, at levels IV and III a higher weight was attributed to the parameter Form, because the limits of the objects from these levels were already previously defined by the vectors of quarters and blocks which were used in the segmentation process. Both Levels I and II had a higher weight attributed to the parameter Color, because the spectral content is more important to distinguish land cover classes than the Form attribute. The segmentation strategy considered was of type Bottom-up, i.e. objects of Level I were successively aggregated until they formed object of Level IV. This strategy was adopted because, according to Hofmann & Reinhardt (2000) the direction of the segmentation process (bottom-up or top-down) affects the limits of the objects and so it is wise to start the segmentation at the level where there are objects of interest.

4. DISCUSSION OF RESULTS

In this paper, due to space limitations, we present only the results of segmentation and the comparison of the classification from both sensors.
The results of the segmentation parameters used for both images were tested and compared, as well as computer time needed (Table 2). In this table it is noteworthy to verify the difference among scale parameters between both images and the processing times. Considering that each segmentation level is associated to a representation scale (i.e. an average size of objects to be extracted) one would expect that the segmentation parameters are the same for both images. Since the spatial resolution of the two sensor systems is quite different (almost the double), different scale parameters are required.

Referring to the processing time one observes that there is quite a difference among processing times between Level I and IV. This is due to the size of the objects which at (I) are quite small in comparison to (IV). Besides that, since the segmentation strategy was bottom-up, all levels were created from the segment aggregation at (I), making this process faster. There are also different processing times among the image data used. This is because of the different pixel size (*Quickbird* has 2,77 times more pixels and a different size than *Ikonos*) resulting in more information to be processed.

Figure 1 shows the classification result of the *IKONOS* scene. A visual analysis indicates that there is confusion among classes "Ceramics" and "Bare soil", while the other classes are apparently quite coherent in an overall analysis. The classification was significantly better than a random classification with z =25,93 (if z >1,96 the result is better than a random classification) with global exactitude of 57,98% and *Kappa* coefficient of 0,54. According to Landis & Koch (1997), the classification obtained can be considered as of good quality, since *Kappa* lies between 0,40 and 0,60.

The classification of the *QUICKBIRD* image is presented at Fig.2. Here, similarly to the IKONOS scene there was also confusion among classes "Ceramics" and "Bare Soil", but in lower proportion. The classification was significantly better than a random classification with z = 26,70 (if z is equivalent or larger than 1,96 the result is better than a random classification at 95% significance), with global exactitude of 0,61 and *Kappa* coefficient of 0,57. Like the former classification, it can also be considered good, according to Landis & Koch (1997).

Comparing both classifications, one concludes that there are no significant quality differences among them. A Z test, performed to verify if there are significant differences among both classifications, obtained Z = 1,01, which indicates, at a 95% significance, that there is no important difference between the confusion matrices.

5. CONCLUSIONS

Referring to the class characterization, 3 types of information were of essential importance for the distinction of objects: 1st contextual information, introduced in some classes, such as spatial restrictions imposed to classes Asphalt Error and Concrete/Dark Asbestos, based on the object localization context, according to specific situations; 2nd spectral attributes (average, standard deviation and others), calculated from HIS channels, which were used to describe several classes and 3rd the customized attributes created to distinguish vegetation (NDVI of object average) and red objects from the remaining classes (3/1 ratio between the average of objects of bands 3 and 1).

From the analysis of classification results one verifies that the approach used presents a strong potential to classify urban land cover for high resolution satellite images. The multi-resolution segmentation considered, allowed the use of information about the relations of objects at different scales. The utilization of knowledge representation in hierarchical networks allowed the establishment of heredity relations between classes as well as class groupings with distinct physical aspects, but coherent semantics (e.g. class of buildings can be grouped in only one class "built-up areas"). As far as the thematic exactitude obtained from data of both orbital sensors is concerned we concluded that both datasets delivered good quality products (*Kappa* around 0,50). Taking into account that *QUICKBIRD* data have a spatial resolution of almost two times better than *IKONOS,* it was expected that the classification results obtained would also deliver a higher thematic exactitude. Nevertheless we found out that the differences of thematic exactitude among both datasets are not significant. However, if the degrees of instability are considered for the choice of the most adequate sensor data, *QUICKBIRD* images are more advantageous because they presented higher stability than *IKONOS.* Analyzing in detail the maps of instability produced by Pinho (2005), one perceives that there is a direct relation between the border definition of an object and its instability degree. Being so, the higher spatial resolution of *QUICKBIRD* data produced more trustful segments and consequently more stable classifications.

6. REFERENCES

Antunes, A.F.B., 2003. **Classificação de ambiente ciliar baseada em orientação a objeto em imagens de alta resolução espacial**. Curitiba. 146 p. Tese (Doutorado em Ciências Geodésicas) – Universidade Federal do Paraná.

Benz, U., Hofmann, P., Willhauck, G., Lingenfelder, I. and M. Heynen, 2004. Multi-resolution, object-oriented fuzzy analysis of remote sensing data for GIS-ready information. In: ISPRS **Journal of Photogrammetry & Remote Sensing** 58, 239-258.

Blaschke, T. & Strobl, J., 2001. "What's wrong with pixels?" Some recent developments interfacing remote sensing and GIS. GIS – **Zeitschrift für Geoinformationssysteme** 6/2001, 12-17.

Definiens, **eCognition: User Guide 3**, 2003. 480 p. available at: http://www.definiens-imagigng.com/down/ecognition

Hofmann, P. & Reinhardt, W., 2000. The extraction of GIS features from high resolution imagery using advanced methods based on additional contextual information – first experiences. In: **ISPRS**, Vol. XXXIII, Amsterdam.

Landis, J.R. & Koch, G.G., 1977. The measurement of observer agreement for categorical data. **Biometrics,** vol. 33 (1), pp. 159-174.

Meinel, G.; Neubert, M. & Reder, J., 2001. The potential use of very high resolution satellite data for urban areas: First experiences with IKONOS data, their classification and application in urban planning and environmental monitoring. In: 2nd International Symposium on Remote Sensing of Urban Areas. **Proceedings**. Regensburg, Germany: Institut für Geographie an der Universität Regensburg, 196-205.

Neubert. M. & Meinel, G., 2005. **Análise de dados do satélite IKONOS baseada em segmentação – Utilização do software de análise de dados *eCognition* para diferentes áreas-testes**. In: Blaschke, T. e Kux, H. Sensoriamento Remoto e SIG avançados, São Paulo: Oficina de Textos, Cap. 11, p.115-124.

Pinho, C.M.D. & Kux, H., 2004. Dados do Quickbird para subsidiar o planejamento urbano: uma proposta metodológica, município de São José dos Campos, SP, Brasil. In: Anais XI Simpósio Latinoamericano de Percepción Remota y Sistemas de Información Espacial. Santiago, Chile, 22-26 Novembro 2004, SELPER.

Pinho, C.M.D.; Rennó, C.D. & Kux, H., 2005. Avaliação de técnicas de fusão aplicadas à imagem Quickbird. [CD-ROM]. In: Simpósio Brasileiro de Sensoriamento Remoto (SBSR) 12, 2005. **Anais**... São José dos Campos:INPE, 4225-4232. CD-ROM. ISBN 85-17-00018-8.

Pinho, C.M.D., 2005. Análise orientada a objetos de imagens de satélite de alta resolução espacial aplicada à classificação de cobertura do solo no espaço intra-urbano: o caso de São José dos Campos – SP. São José dos Campos, 179 p. Dissertação (Mestrado em Sensoriamento Remoto) – INPE, 2005.

PMSJC – Prefeitura Municipal de São José dos Campos; Dados Gerais, 2005, available at: <http://www.sjc.sp.gov.br/html/cid_sjcdados.htm>

Rego, L.F.G. & Koch, B., 2003. Automatic classification of land cover with high resolution data of Rio de Janeiro City, Brazil: comparison between pixel and object classification. [CD-ROM]. In: Carstens, J. (ed.) The Photogrammetry, Remote Sensing and Spatial Information Sciences. **Proceedings**. Regensburg, Germany.

Rego, L.F.G., 2003. **Automatic land-cover classification derived from high-resolution IKONOS satellite image in the urban Atlantic Forest in Rio de Janeiro, Brazil be means of an object-oriented approach**. Freiburg. 193 p. (Forstwissenschaftliche Fakultät), PhD. Thesis Albert-Ludwigs-Universität.

Schiewe, J. & Tufte, L., 2005. **O potencial de procedimentos baseados em regiões para a avaliação integrada de dados de SIG e Sensoriamento Remoto**. In: Blaschke, T. & Kux, H. Sensoriamento Remoto e SIG avançados. São Paulo Oficina de Textos, cap. 5, 51-60.

Table 1 - Description of segmentation levels used

Level	Objects of interest	Objective	Files used	Main Parameter considered
IV	Quarters	To generate urban indicators by quarters.	Base of quarters	Form
III	Blocks Streets	To be a base for restrictive rules for the occurrence of certain classes.	Bases of quarters and blocks	Form
II	Large land cover classes: Vegetation, Built-up area, Bare soil, Shadow	To generate a vegetation map in a rougher scale to restrict the existence of some classes of Level I	Bases of quarters and blocks, 4 multi-spectral channels of fused image	Color
I	Land cover classes: arboreal, grass, swimming pool, asphalt, bare soil, tile of clear ceramics, etc.	To map classes of land cover in detail	Bases of quarters and blocks, 4 multi-spectral channels of fused image	Color

Source: Pinho (2005)

Table 2 – Scale parameters, form and compactness, number of objects and processing time, according to segmentation level

Segmentation level	**IKONOS**	**QUICKBIRD**
(I). Land cover	Scale: 15 Form: 0,3 Compactness: 0,5 Processing time: 37' Nr. of objects: 457.517	Scale: 20 Form: 0,3 Compactness: 0,5 Processing time: 2' 03" Nr. of objects: 439.849
(II). Vegetation and non-vegetation	Scale: 40 Form: 0,3 Compactness: 0,5 Processing time: 4' Nr. of objects: 89.191	Scale: 50 Form: 0,3 Compactness: 0,5 Processing time: 10' Nr. of objects: 103.174
(III). Blocks and Streets	Scale: 1000 Form: 0,9 Compactness: 0,5 Processing time: 09' Nr. of objects: 5.352	Scale: 1000 Form: 0,9 Compactness: 0,5 Processing time: 17' Nr. of objects: 5964
(IV). Quarters	Scale: 50.000 Form: 0,9 Compactness: 0,5 Processing time: 10' Nr. of objects: 1.438	Scale: 50.000 Form: 0,9 Compactness: 0,5 Processing time: 11' Nr. of objects: 2.359

Source: Pinho (2005)

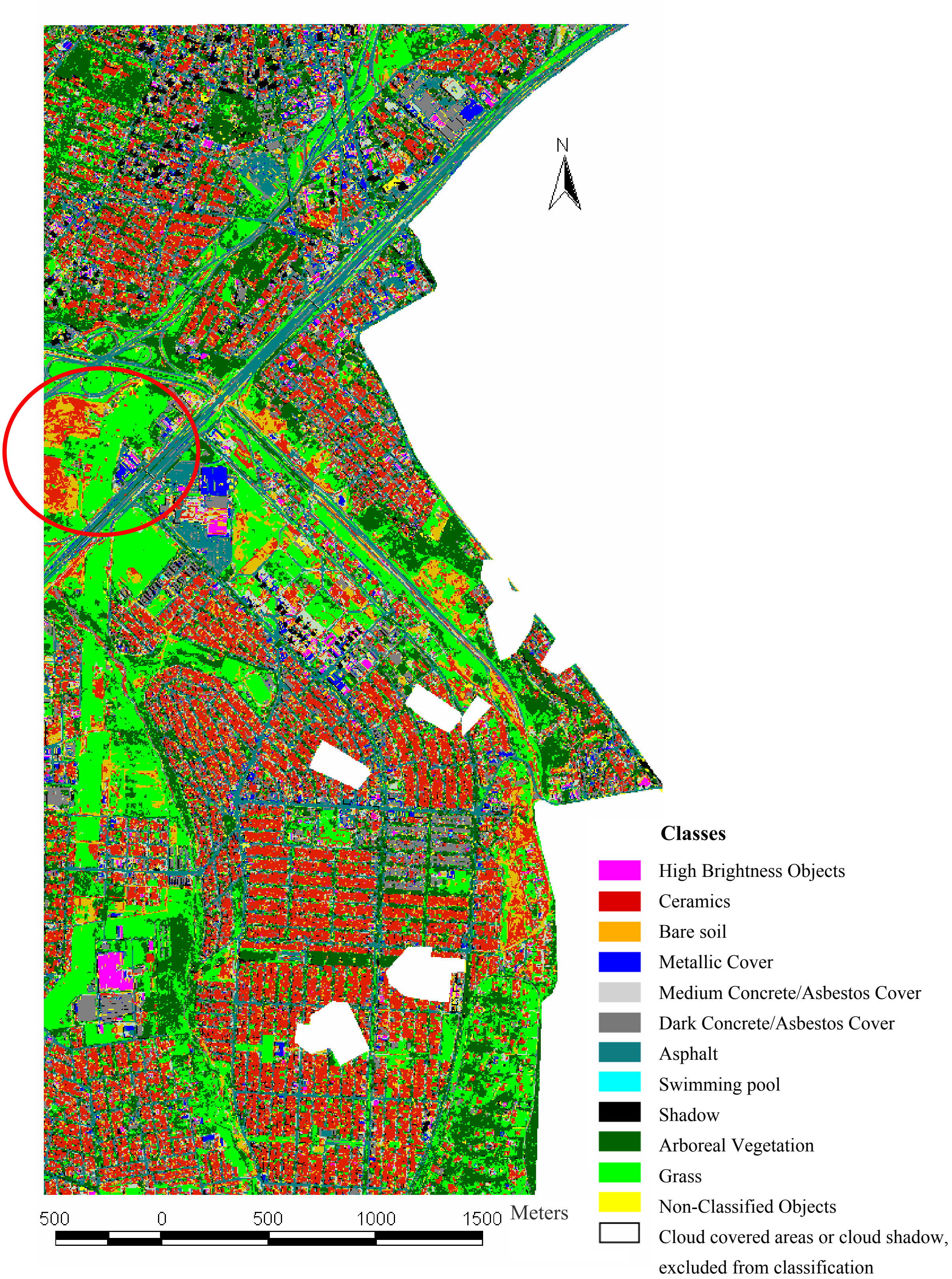

Figure 1 – IKONOS land cover classification.

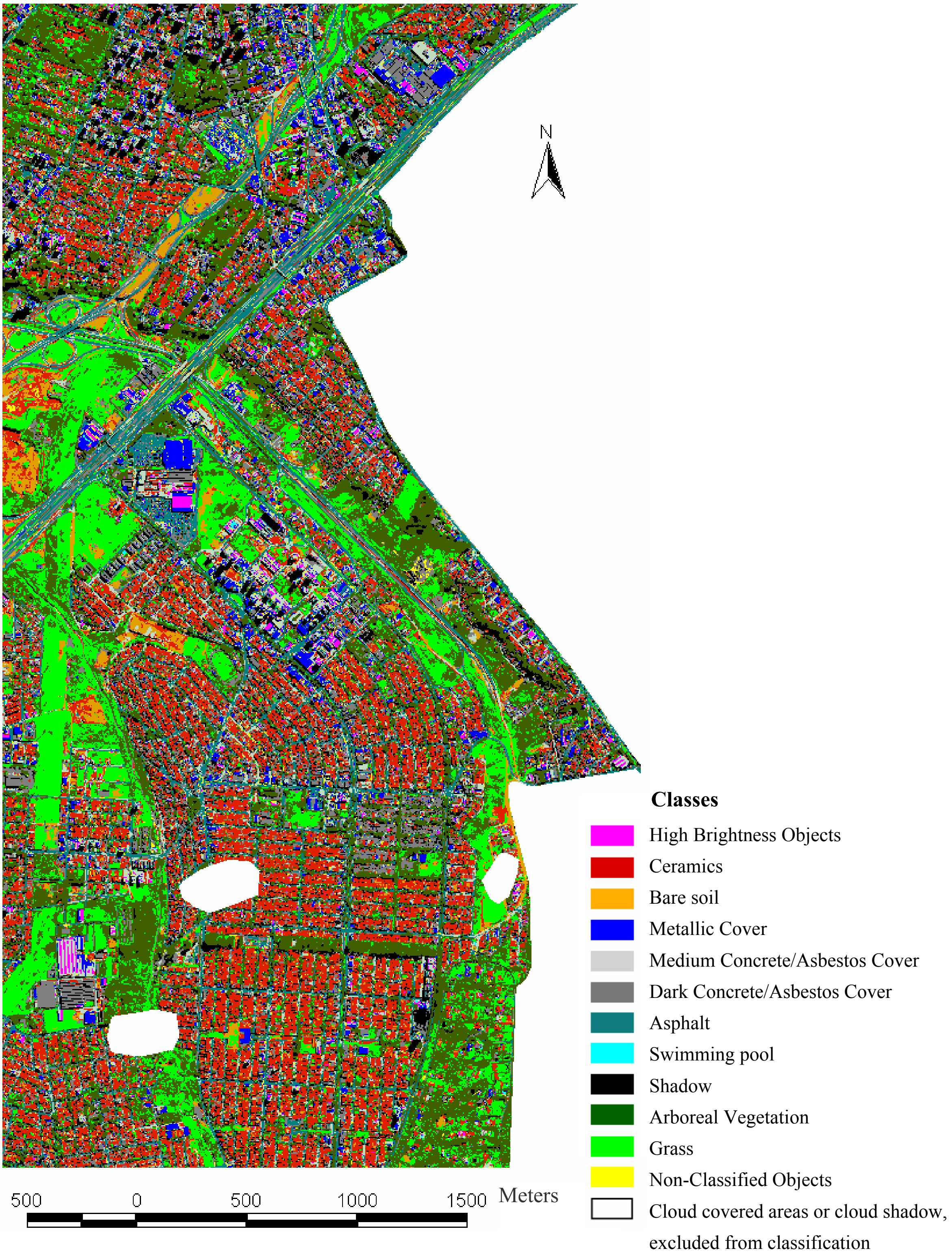

Figure 2 – QUIICKBIRD land cover classification.