ISSN 1980-7694 ON-LINE

THE USE OF HIGH-RESOLUTION IMAGING TO EVALUATE GREEN AREAS IN THE CITY OF SAO PAULO – BRAZIL

Juliana Amorim da Costa[1], Demóstenes Ferreira da Silva Filho[2], Jefferson Lordello Polizel[3]

ABSTRACT

The presence of green areas brings numerous improvements to cities and provides better life quality for residents, with aesthetical, leisure and educational functions. The growth of Brazilian cities was not supported by urban planning that could have reserved spaces for green areas, as is the case of São Paulo city, a metropolis that has social and environment problems. Geoprocessing and remote sensing have been successfully used to evaluate urban areas and, mainly regarding the presence of urban forest. Thus, we used high definition imaging from Ikonos and Quickbird satellites, in the years 2002, 2004, 2006 and 2008, to evaluate the presence of urban forest in three zones of São Paulo city, using the concept of greenways: Mooca, Sé and Pinheiros administrative regions. For that purpose, we applied different methods to obtain data on the urban area of São Paulo city, through high-resolution imaging classification techniques and the implementation of the Urban Forest Index. The method Stepwise Linear proved to be most appropriate for this research and Pinheiros administrative region had the best value for Urban Forest Index.

Keywords: Remote sensing; Automatic classification; Urban forestry; Urban forest index

RESUMO

A presença de áreas verdes nas cidades traz inúmeras melhorias a estas e melhora a qualidade de vida do cidadão, exercendo funções estéticas, de lazer e educacional. O crescimento das cidades brasileiras não foi acompanhado por um planejamento urbano que reservasse espaços para o verde, como é o caso da cidade de São Paulo, uma metrópole que possui problemas sociais e ambientais. As ferramentas de geoprocessamento e sensoriamento remoto vêm sendo utilizadas com sucesso para analisar o tecido urbano e, em especial, a arborização presente na cidade. Assim, fez-se uso de imagens de alta resolução, dos satélites Ikonos e Quickbird, dos anos de 2002, 2004, 2006 e 2008, para avaliar quanto ao quesito arborização três regiões da cidade de São Paulo: subprefeitura da Mooca, subprefeitura da Sé e subprefeitura de Pinheiros. Para isto foram aplicados diferentes métodos de obtenção de dados físicos do tecido urbano, por meio de técnicas de classificação de imagens de alta resolução, juntamente com a aplicação do Índice de Floresta Urbana. O método de classificação que demonstrou ser o mais adequado para este trabalho foi o Stepwise Linear e a região que obteve melhor índice de floresta urbana foi a da subprefeitura de Pinheiros.

Palavras-chave: Sensoriamento remoto; Classificação automática; Arborização urbana; Índice de floresta urbana.

[1] Mestre em Ciências na Área de Recursos Florestais e Gestora Ambiental pela Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, SP – juliana.costa@usp.br.
[2] Professor Doutor, Departamento de Ciências Florestais, Escola Superior de Agricultura “Luiz de Queiroz” – Universidade de São Paulo, Piracicaba, SP – dfilho@usp.br
[3] Técnico do Laboratório de Métodos Quantitativos, Departamento de Ciências Florestais, Escola Superior de Agricultura “Luiz de Queiroz” – Universidade de São Paulo, Piracicaba, SP – jlpolize@esalq.usp.br

INTRODUCTION

São Paulo city is one the largest cities in the world with a population circa ten million people (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, IBGE, 2007). However, its urbanization process did not follow a specific policy to guide its rapid growth (BOLAFFI, 1992). In this unplanned urbanization, we observe that few spaces were reserved for greenways and environmental preservation (ALVAREZ; PENTEADO, 2006).

Examples that reflect the absence of adequate public policies for the city of São Paulo are observed in the economic, social and environmental sectors, resulting in the degradation of quality of life for the population caused by high levels of pollution, huge amounts of residues, transformation of green areas into impermeable ones, high levels of urban violence, social segregation, which compromise the physical and mental health of the population that no longer enjoys the social space on the streets due to urban violence (BRAGA, 1999; PILOTTO, 2003).

The establishment of green areas in the city contributes to mitigate several problems, such heat islands, floods and respiratory diseases, as well as to the aesthetic of the city with options for leisure and education. Therefore, it is imperative to assess these areas for an adequate planning of urban afforestation.

Remote sensing techniques and geoprocessing are important tools to obtain information on visualization and quantification of urban afforestation and its structure, allowing a periodical evaluation of the areas, which constitutes an efficient and inexpensive method (SILVA FILHO, 2004).

Remote sensing provides high-resolution imaging, for example, images provided by satellites IKONOS and Quickbird. Satellite IKONOS is operated by the enterprise *Space Imaging* and records electromagnetic radiation from targets in several spectral ranges with spatial resolution of 1m x 1m of pixel side. Satellite Quickbird was developed by *DigitalGlobe*, and is characterized for its high precision (QUICKBIRD, 2008). It offers 0.61m x 0.61m of pixel side for panchromatic imaging and 2.8m x 2.8m of pixel side for multispectral imaging.

Satellites imaging is necessary for a satisfactory extraction of urban imaging. In the imaging processing, we have the fusion process and automatic classification of images.

Image fusion allows to maintain spectral resolution obtained from multispectral imaging with better spatial resolution from the panchromatic imaging (CENTENO; RIBEIRO, 2007). There are different methods for this process.

Pinho et al. (2005) show three types of image fusion performed in Quickbird imaging: images that use a model of spatial domain, images of spectral domain and those that use algebraic operations. The author highlighted the technique known as Brovey, which obtained images with significant color variation, ranging from bright green to dark blue and difference in intensity for afforested areas. It operates through an algebraic model with arithmetic functions pixel by pixel, promoting color normalization.

The classification process is used to obtain information on imaging that ensures a satisfactory analysis of the area. There are several types of automatic classification, including classifications that require more intervention of the user and the need to collect samples of pixels that constitute the program, supervised classifications and classifications that require the definition of some parameters, as well as unsupervised classifications.

In the supervised classifications, we can mention the methods of Maximum Likelihood and Stepwise Linear.

The Maximum Likelihood method assesses quantitatively the variance and the covariance of standards of spectral responses of pixel samples collected in the imaging, assuming that they have normal distribution, and uses statistics of probabilities to identify which class a given pixel belongs to (LILLESAND et al., 2004). The Stepwise Linear method uses linear discriminant analysis (LDA) to identify the class of a given set of pixels (MICROIMAGES, 2006).

For unsupervised automatic classifications, we have, among others, the methods K-Means and ISODATA

(*Iterative Self-Organizing Data Analysis*). The K-Means method groups pixels in the quantities of classes defined by the user, calculating the centroid of each class to distribute these pixels. ISODATA also uses the centroid of each class to group pixels, in addition to applying fusion, exclusion and division techniques for imaging classification (LILLESAND et al., 2004).

The use of these techniques of geoprocessing and remote sensing were assessed in green areas of three regions of the city of São Paulo – Brazil.

This study aimed to assess urban afforestation in three districts in São Paulo city: Mooca, Sé and Pinheiros. The main objectives were:

(i) To analyze different models for obtaining physical data of the urban environment of São Paulo City using remote sensing and geoprocessing systems to define the best method to identify critical areas;

(ii) To analyze satellite imaging of different times of São Paulo city, to measure transformations of green areas in the three study sites;

(iii) To apply the Urban Forest Index (UFI) proposed by Silva Filho et al. (2005).

MATERIALS AND METHODS

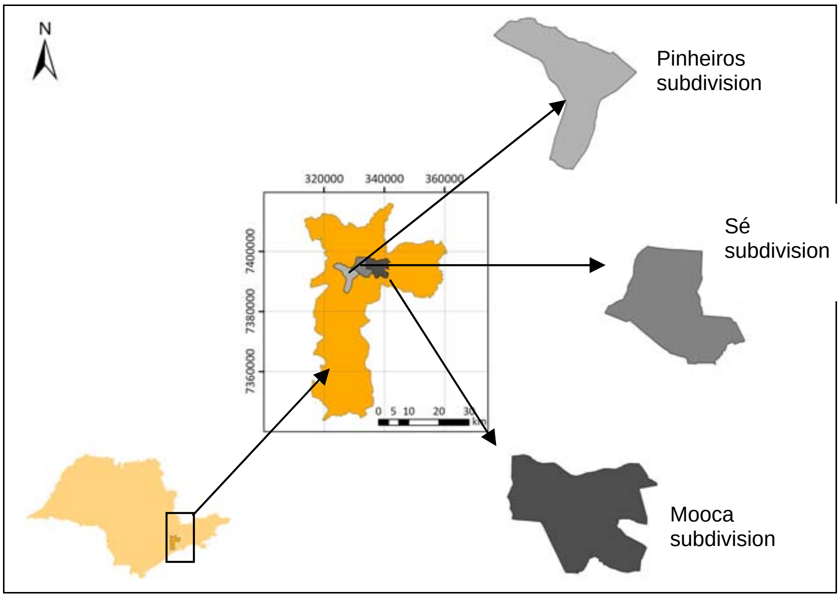
Study area

São Paulo City

The municipality of São Paulo covers 1,530 km², at 780m above sea level, situated at latitude 23°32.0'S and longitude 46°37.0'W, in the state of São Paulo, in the Southeastern Brazil (CIDADE DE SÃO PAULO, 2008), with a population circa 10,886,518 inhabitants (IBGE, 2007). The climate is subtropical (Cwa type according to Köppenn classification), with average annual temperatures of 19°C.

Within this region, we studied and analyzed the districts of Mooca, Sé, and Pinheiros (Figure 1).

Figure 1. Study area



The district of Mooca covers an area of 35.2 km^2 and is situated in the eastern region of São Paulo city. This subdivision includes the following districts: Mooca, Água Rasa, Belém, Tatuapé, Pari and Brás, with a population of 308,161 inhabitants, according to the census conducted in 2000 (IBGE) (PORTAL DA PREFEITURA DA CIDADE DE SÃO PAULO, 2009), and population density of 8,754.57 inhab/km^2.

Located in the center of the study area, the subdivision of Sé covers an area of 26.2 km^2. This subdivision responds for the districts of Bom Retiro, Santa Cecília, República, Sé, Consolação, Bela Vista, Liberdade and Cambuci, and has a population of 373,914 inhabitants, according to the census conducted in 2000 (IBGE) (PORTAL DA PREFEITURA DA CIDADE DE SÃO PAULO, 2009), and population density of 14,271.53 inhab/km^2.

The subdivision of Pinheiros, situated in the western region of the city, covers an area of 31.7 km^2. This subdivision encompasses the districts of Alto de Pinheiros, Pinheiros, Itaim Bibi and Jardim Paulista. It has 272,574 inhabitants, according to the census conducted in 2000 (IBGE) (PORTAL DA PREFEITURA DA CIDADE DE SÃO PAULO, 2009), and a population density of 8,598.55 inhab/km^2.

We used the Center for Quantitative Methods of the Forestry Science Department from the College of Agriculture "Luiz de Queiroz" (ESALQ), Universidade de São Paulo (USP), located in Piracicaba city, São Paulo state, Brazil. We also performed field trips to the study areas.

Imaging processing

In this stage, we used imaging from satellite IKONOS from the year 2002, orthorectified from the digital model of elevation, delivered in four spectral waves, in the visible domain (RGB), with red (R), green (G) and blue (B) waves and the near infrared, with spatial resolution of 1 meter and radiometric resolution of 11 bits (MOREIRA, 2005).

The imaging was obtained by Geologic Institute, and belonged to the Secretariat for Environment of the State of São Paulo, in the year 2003, through FUNCATE (Foundation for Science, Applications and Spatial Technologies). The images are mosaicked; therefore, it was not possible to apply radiometric corrections.

The original imaging was carried out by satellite IKONOS, operated by *Space Imaging*, in October 2002 and complemented by new acquisitions of images in 2003.

We also used imaging from satellite Quickbird developed by *Digital Globe*. We obtained images of the subdivisions of Mooca, Sé and Pinheiros for the years 2004, 2006 and 2008. However, for the year 2004, the images available in archives did not cover the entire region of the subdivision of Pinheiros. For the year 2006, the images available in archives did not cover the entire area of the subdivision of Sé, and there was no imaging available for the subdivision of Pinheiros. The images are in the coordinate system UTM (*Universal Transverse Mercator*), zone 23, datum WGS-84.

To analyze the images obtained, we used the geoprocessing programs ArcGIS 9.2, developed by *ESRI* and TNTmips 2009, developed by *Microimages*.

Imaging fusion of Quickbird

Imaging from Quickbird was subjected to the process for panchromatic imaging fusion with multispectral, through techniques for geoprocessing of the program TNTmips 2009, using the method Brovey for processing. Tests were carried out to identify which combination of waves would be more interesting for the analysis of urban afforestation of the study sites.

The fusion tests were validated through tests of supervised automatic classification, which are explained in the following items. The imaging used for the tests was obtained from the Quickbird in 2008.

The following wave combinations of imaging were analyzed:

(i) Test 1: use of blue and red waves and near infrared in addition to the panchromatic wave;

(ii) Test 2: use of four multispectral waves in addition to the panchromatic wave;

(iii) Test 3: use of green and red waves and near infrared in addition to the panchromatic wave.

Automatic classification of high-resolution imaging

The classifications tested comprised the supervised classification, and within this classification, the Maximum Likelihood and the Stepwise Linear methods. The classifications were assessed by discrete multivariate analysis as Kappa statistics and visual and comparative interpretation; and the unsupervised classification using the ISODATA and K-means methods, which were assessed through comparison with original images with other classification methods. The Kappa index is obtained by formulas 1, 2 and 3 (LANDIS; KOCH, 1977).

$$K = \frac{Po - Pc}{1 - Pc} \qquad (1)$$

$$Po = \frac{\sum_{i=1}^{M} n_{ij}}{N} \qquad (2)$$

$$Pc = \frac{\sum_{i=1}^{M} n_{i+} n_{j+}}{N^2} \qquad (3)$$

Where: Po = percentage of occurrence observed; Pc = percentage of expected random concordance; M = number of classes found in the error matrix; n_{ij} = number of observations in line *i* and column *j*; n_{i+} and n_{j+} = totals margins of line *i* and column *j*, respectively; and N = total number of sample units contemplated in the matrix.
According to Landis and Koch (1977), we have the following interpretation of this index (Table 1):

Table 1 – Interpretation of Kappa Index

Kappa values (%)	Accuracy of classification
0	Null
0 - 20	Poor
21 – 40	Weak
41 - 60	Moderate
61 - 80	Good
81 - 100	Optimal

To validate the supervised classification tests, we also analyzed the dendrogram of each classified image.
After classification, we applied an image filter to the classified image, called Hole-Filling, which replaced the class of a pixel for another found in most neighboring cells, removing the images found in an isolated class. It is possible to choose the size of the area to be filtered and in this study, we chose the size 3x3.
The classes used were: tree crowns, grasslands, asphalt, cement floors, ceramic shingles, grey shingles, dark shingles, metal shingles, shade, exposed soil, among others. These are the classes used for the characterization of land use in studies carried out by the Laboratory of Urban Afforestation of ESALQ/USP.

Calculation of Urban Forest Index

To analyze the tree cover of the study areas, we calculated the Urban Forest Index (UFI) proposed by Silva Filho et al. (2005). It is an indicator to rate afforested spaces that relate these spaces to other elements in the urban landscape. The UFI is obtained through formula 4:

$$IFU = PAI + PAC \quad (4)$$

Indexes for PAI (ratio between afforested spaces and impermeable free spaces) and PAC (ratio between afforested spaces and built-up spaces) are obtained from formulas 5 and 6:

$$PAI = \frac{ELA}{(ELA + ELI)} \quad (5)$$

$$PAC = \frac{ELA}{(ELA + EC)} \quad (6)$$

Where: ELA represents the afforested space (tree crown class); ELI represents the impermeable free space (asphalt and cemented floor classes); EC is the built-up space (ceramic, metallic, dark and gray shingles).

UFI ranges between zero and two, being that the higher the index value, the higher the percentage of tree cover in relation to other elements in the urban environment (SILVA FILHO et al., 2005).

RESULTS AND DISCUSSION

Fusion of Quickbird imaging

We carried out the fusion of multispectral waves of spatial 2.8-meter resolution of Quickbird imaging, at different combinations, with the panchromatic wave, of 0.61-meter spatial resolution, using the program TNTmips 2009, which has a specific function for Quickbird imaging fusion, in the Brovey method.

This method combines multispectral waves of low spatial resolution, represented as R (red), G (green) and B (blue), of an image with the panchromatic wave, of high resolution. This method allows the use of arithmetic techniques of sum and multiplication (VRABEL, 1996).

The different wave combination of multispectral imaging provides different spectral responses, because wave combinations and lengths are different for the same target of a given image.

Based on the supervised automatic classification, we performed a visual and dendrogram analysis in the program TNTmips 2009. We observed that the different combinations of multispectral waves used for image fusion influences the results of automatic classification, mainly in terms of percentage of each class found in the imaging. To exemplify, Table 2 shows the percentage of classes in the subdivision of Mooca using classification with the Maximum Likelihood classifier.

Table 2 - Percentage of classes for Mooca subdivision using the method of Maximum likelihood Classification

Class	Test 1 (%)	Test 2 (%)	Test 3 (%)
Pools	0.06	0.08	0.04
Tree crowns	5.45	7.39	9.16
Exposed soils	2.57	2.54	3.78
Asphalt	14.10	14.95	14.40
Grasslands	7.06	2.40	10.07

Dark shingles	33.85	24.02	30.64
Ceramic shingles	3.72	3.39	4.05
Shades	12.81	15.85	11.96
Metallic shingles	0.25	0.23	0.60
Gray shingles	3.84	3.79	2.40
Lakes/Rivers	2.17	0.01	0.42
Cemented floors	11.71	11.66	5.90
Others	2.41	13.70	5.58

We observe the existence of a marked different between the percentage values found for each type of wave combination in the class “tree crown”, the major focus of this study.

Because of the different spectral response of the targets studied, depending on the fusion, we observe difference in the pixel quality found for each class.

Moreover, the dendrogram analysis allows to evaluate the separation level of targets. Therefore, the most adequate combination of waves was that combination that showed less separation between targets that have similar material in their constitution, as in the case of tree crowns and grasslands, which show high separation between the targets.

Thus, we confirmed that the most adequate fusion for data extraction on tree cover was the combination of blue and red waves and of the near infrared fused with a panchromatic wave (Test 1).

Obtaining physical data from high-resolution imaging

Unsupervised classifiers

The user should provide the number of probable spectral classes, the minimum distance desired between values of digital levels of two classes and the number of iterations performed to the algorithm. This method allows the grouping of homogenous pixels in *n* spectral classes (MOREIRA, 2005). We limited the algorithm to 13 classes and 20 iterations.

The tests using K-means show that it is not appropriate for extracting data on urban landscaping in high-resolution imaging, either from IKONOS or from Quickbird.

We observed that K-means makes confusions between classes. There are areas classified as “exposed soils” that were indeed “gray shingles” or “cemented floors”. In addition to “ceramic shingles” that were classified as “grasslands”. “Dark shingles”, “cemented floors” and “asphalt” were not differentiated by the algorithm.

The dendrogram analysis allowed to observe the level of separation between the classes. We observed elements that should have a lower separation level, because they are composed of material of similar spectral responses, which were distant and near elements of thoroughly distinct spectral response.

The class “tree crowns”, for the same reason, should by near the class “grasslands”; however, it was not. It is nearer elements that should have a higher separation level, given that its spectral responses are quite different, such as the class “cemented floors”.

The unsupervised classification method ISODATA is similar to K-means, but it incorporates criteria of division, combination and discharge for classes in order to obtain a satisfactory number of base classes. It is based on the grouping analysis where pixels with similar characteristics are identified (MICROIMAGES, 2006). We identified a limit of 13 classes and 20 iterations in the program.

The tests with ISODATA showed that this method is not appropriate for extracting data on urban landscape using high-resolution imaging, either from IKONOS or from Quickbird.

We observed that ISODATA cannot individuate some elements, such as “ceramic shingles” and “pools” and does not differentiate other targets. We also observed a strong mixture between the elements “cemented floors” and “asphalt”, as well as “tree crowns” and “grasslands”.

Valerio et al. (2008) also indentified this confusion between classes in the ISODATA method. The author generated theme maps for land use and water quality in the water reservoir Rio Manso in the municipality of Cuiabá – Mato Grosso state – Brazil – and compared the ISODATA method with the supervised method Maximum Likelihood, which showed better correlation between original and classified imaging.

In the map of water quality, which had fewer elements to be classified than in the map for land use, the ISODATA method showed lower confusion of classes.

The dendrograms of these images, as in the case of K-means classifier, showed higher separation between classes of similar spectral characteristics than between classes of different spectral responses.

Supervised classifiers

Supervised automatic classifiers are those that require the creation of a training to be applied. The training should collect the samples distributed all over the image to be representative.

The results obtained with Maximum Likelihood showed that it underestimates the amount of tree cover, given that it classifies grasslands and some areas of exposed soils as tree cover.

Ribeiro and Centeno (2001) also observed this fact when classifying images from Landsat M. The authors identified that classes spectrally near are not separated in the classification process, for example, classes of “crops” and “pastures”. The authors conclude that a higher number of samples in the training may generate a better result.

Ouma and Tateishi (2008) carried out a study on data extraction for tree cover in urban areas using Quickbird imaging and concluded that Maximum Likelihood underestimated the quantity of urban trees. The authors observed that this algorithm has difficulties to distinguish statistically pixels belonging to classes “grasslands”, “shrubs”, “tree crowns” and “shade”.

The Linear Stepwise method also showed certain confusion between classes, such as “grasslands” and “tree crowns”. However, a visual analysis of the tests allowed to observe that this confusion is reduced when compared to classifications using the Maximum Likelihood method.

Weber, Petropoulou and Hirsch (2005) studied the development of urban areas in the Athens, Greece, using geoprocessing techniques. The authors performed supervised classification using the Linear Stepwise method in satellite imaging from SPOT and verified that this classifier has the capacity to differentiate the targets in the urban landscape, in terms of characteristics like presence/absence of tree cover and presence/absence of built-up areas. Therefore, it presented as an adequate classifier for urban areas.

The dendrograms analyzed showed a lower separation level in targets of similar spectral responses, such as “tree crowns” and “grasslands” and a higher separation level between targets with distinct spectral response. The Linear Stepwise method is more accurate in terms of physical data regarding “tree crowns”, major focus of this study.

Therefore, to obtain data on tree cover of the study sites, we used the Linear Stepwise method for classification of high-resolution imaging.

Currently, new classification techniques are also used in high-resolution imaging, such as the object-targeted classification, which uses several other parameters to perform the classification. We highlight, then, the importance of studies that compare these techniques to identify which classification technique shows better results for each type of study.

Quantification of tree cover in urban areas

We used imaging from different years of the study area to quantify the tree cover in the site. The images were collected in different months. The Quickbird imaging is from August 2004, November 2006 and July 2008. Therefore, the images are from different times of the year, when tree crowns may be more or less vigorous, influencing, thus, the qualitative analysis of the class “tree crowns” and this information should be carefully considered.

Subdivision of Mooca

We carried out a field study to characterize the site and observed that the site is characterized, mainly, by commercial areas, displaying therefore a high flux of people during the week and on Saturdays, which causes some degradation to the site in terms of garbage disposed on the streets and lack of care with public assets. We did not observe significant road afforestation. Table 3 shows the percentages of elements found in the site.

Table 3 – Land cover of the subdivision of Mooca in 2002, 2004, 2006 and 2008

Class	2002 (%)	2004 (%)	2006 (%)	2008 (%)
Pools	0.06	0.03	0.04	0.04
Tree crowns	2.78	1.98	4.35	3.13
Exposed soils	9.04	2.45	4.69	4.51
Asphalt	20.60	29.53	17.50	20.10
Grassland	1.18	1.50	1.89	3.55
Dark shingles	19.31	21.78	37.53	27.41
Ceramic shingles	12.88	1.42	6.93	2.52
Shades	14.44	19.97	6.66	26.33
Metallic shingles	1.02	0.69	3.66	0.53
Gray shingles	7.73	2.57	3.27	3.85
Lakes/Rivers	-	0.60	0.42	0.15
Cemented Floors	6.72	7.51	12.62	6.67
Others	4.25	9.99	0.45	1.22

The classifications were assessed through Kappa statistics (Figure 2). In the error matrix, besides the Kappa index, we should analyze values presented by each class of error matrix, i.e., the number of representative pixels of each class. In the matrix presented, these numbers are highlighted in red. For the classification results to be considered satisfactory, these numbers should be displayed as "stairs", representing the higher number of pixels sampled in a class that actually belongs to that class. All error matrices showed this behavior, regarding the classifications performed.

All classifications were rated as optimal, according to Kappa statistics, as observed in the Table 4 (LANDIS; KOCH, 1977).

Figure 2 – Error matrix of IKONOS imaging classification for subdivision of Mooca in 2002

	Pool	Crown	Grassland	Shingles	Exp. Soil	Asphalt	Shade	M. shingles	C. shingles	Cem. floor	D. shingles	G. shingles		
	Ground Truth Data													
Name	Piscina	Copa de	Relvado	Telha az	Solo exp	Asfalto	Sombra	Telha me	Telha ce	Piso cin	Telha es	Telha ci	Total	Accuracy
Piscina	1730	0	0	0	0	0	0	0	0	0	0	0	1730	100.00%
Copa de	0	1650	5	0	0	0	0	0	4	0	0	0	1659	99.46%
Relvado	0	141	2555	0	0	0	0	0	28	0	0	0	2724	93.80%
Telha az	1	1	0	498	0	2	0	0	0	2	11	4	519	95.95%
Solo exp	0	0	0	0	1741	1	0	0	153	46	2	0	1943	89.60%
Asfalto	0	0	0	0	0	1384	0	0	0	5	497	76	1962	70.54%
Sombra	0	0	0	0	0	0	3873	0	0	0	183	0	4056	95.49%
Telha me	0	0	0	0	0	0	0	1503	0	5	0	0	1508	99.67%
Telha ce	0	26	166	0	4	0	0	0	556	3	0	0	755	73.64%
Piso cin	0	0	0	0	101	0	0	0	0	361	0	72	534	67.60%
Telha es	0	0	0	4	0	283	40	0	3	0	1863	0	2193	84.95%
Telha ci	18	0	0	0	9	23	0	0	0	27	0	3277	3354	97.70%
Total	1749	1818	2726	502	1855	1693	3913	1503	744	449	2556	3429	22937	
Accuracy	98.91%	90.76%	93.73%	99.20%	93.85%	81.75%	98.98%	100.00%	74.73%	80.40%	72.89%	95.57%		

Classification Data

Overall Accuracy = 91.52% Khat Statistic = 90.49%

Juliana Amorim da Costa et al..

Table 4 – Values Kappa and Accuracy of classified images from Mooca subdivision

Assessment	2002 (%)	2004 (%)	2006 (%)	2008 (%)
Kappa	90.49	85.61	93.47	85.63
Accuracy	91.52	87.10	94.37	87.06

The classes were distributed according to the following groups for UFI calculation (SILVA FILHO et al., 2005):

(i) Wooded free spaces: tree crowns and grasslands;

(ii) Permeable free spaces: exposed soil;

(iii) Impermeable free spaces: cemented floors and asphalt;

(iv) Built-up spaces: ceramic shingles, metallic shingles, dark shingles and gray shingles;

(v) Water spaces: lakes/rivers and pools;

(vi) Others: shades and others.

We identified in the class for "others", heliports and sports courts. The class "lakes/rivers" was "masqueraded" (removed from imaging for classification) in the IKONOS imaging in 2002, because it was heavily confused with other classes. Moreover, it is not significantly quantitative for the site.

Clouds and shades are factors that jeopardize classification (RIBEIRO; CENTENO, 2001). Therefore, we created a special class for shade and clouds were not considered in the classification methods by using a mask in these areas.

The class "shade" influences the percentages of other classes, given that it varies from image to image and hides elements in the images. Thus, we can observe some drastic variations in percentages in the table at certain moments. However, the main focus of this study, the class "tree crowns", did not undergo drastic changes along the years.

We, therefore, obtained the following results for UFI (Table 5).

Table 5 – UFI for the subdivision Mooca

Period	UFI
2002	0.155945
2004	0.120363
2006	0.204238
2008	0.188283

The small presence of afforested areas observed in the site was confirmed by the low UFI for the study period. The index was slightly increased during the years 2002 and 2008, and a small decrease was observed in 2006 and 2008.

Silva Filho et al. (2005) applied UFI for nine neighborhoods in the city of Piracicaba – São Paulo state – Brazil. The lowest value was found in the Cidade Alta neighborhood, with a UFI of 0.445. Even being the lowest value for the city, it is higher than that found for the subdivision of Mooca in São Paulo city, which demonstrates the reduced number of trees in the sites, and the need for public policies to increase tree cover and provide education to value urban afforested spaces.

Subdivision of Sé

We performed a field study to characterize the site. In this area, there is a mix of residential with commercial and even industrial areas. The central region of the site is more degraded, mainly, in terms of public assets. We did not observe marked presence of road afforestation, despite some wooded squares, such as Praça da República.

Table 6 shows the distribution of elements found in the subdivision of Sé.

Table 6 – Land cover of the subdivision Sé in 2002, 2004, 2006 and 2008

Class	2002 (%)	2004 (%)	2006 (%)*	2008 (%)
Pools	0.03	0.04	0.03	0.03
Tree crowns	6.96	3.05	6.87	4.99
Exposed soils	4.62	1.51	2.08	2.22
Asphalt	12.78	21.26	16.90	13.88
Grasslands	0.80	1.47	1.60	4.51
Dark shingles	23.96	25.61	26.20	26.55
Ceramic shingles	5.47	1.49	12.45	0.65
Shades	10.56	31.29	9.06	35.26
Metallic shingles	2.40	0.40	3.42	0.60
Gray shingles	3.05	7.96	3.57	2.62
Lakes/Rivers	13.31	-	-	-
Cemented floors	12.97	4.63	14.26	5.85
Others	3.10	1.30	3.56	2.89

*Incomplete imaging

All classifications are rated as optimal, according to Kappa statistics, as observed in Table 7 (LANDIS; KOCH, 1977).

The classes were distributed in the same specific groups as used in the analysis of the subdivision of Mooca. We obtained the following results for UFI (Table 8):

Table 7 – Values of Kappa and Accuracy for image classification from Sé subdivision

Assessment	2002 (%)	2004 (%)	2008 (%)
Kappa	95.47	89.25	87.72
Accuracy	96.24	92.03	89.37

Table 8 – UFI for Sé subdivision

Period	UFI
2002	0.379127
2004	0.184591
2008	0.342781

The small presence of afforested areas found in the site was confirmed by the low UFI for the study period. The index underwent a decrease from 2002 to 2004, and there was an increase from 2004 to 2008.

In comparison to the study carried out by Silva Filho et al. (2005) which applied the UFI to neighborhoods of Piracicaba city – São Paulo state – Brazil –, the lowest value found in a neighborhood of Piracicaba was 0.445 and it is still higher than the values found for Sé subdivision in São Paulo city.

Subdivision of Pinheiros

Comparing to the other sites, we observed a higher number of road afforestation in this area, where there is predominance of new constructions with residential characteristics.

The study was jeopardized by the factors for the images in 2004 and 2006, because for this subdivision, the imaging for 2004 is incomplete and there is no imaging in records for the year of 2006. Therefore, we disregarded the UFI calculation. Table 9 shows the distribution of the elements found in the site.

Table 9 – Land cover for the subdivision of Pinheiros in 2002, 2004 and 2008

Class	2002 (%)	2004 (%)*	2008 (%)
Pools	0.53	0.12	0.08
Tree crowns	6.89	6.34	7.93
Exposed soils	10.45	2.53	1.68
Asphalt	13.57	16.07	20.76
Grasslands	1.37	1.55	10.48
Dark shingles	33.14	32.02	15.31
Ceramic shingles	7.44	2.38	1.16
Shade	12.98	27.13	33.10
Metallic shingles	3.46	0.85	0.71
Gray shingles	4.13	1.82	1.76
Lakes/Rivers	-	-	-
Cemented floors	6.03	7.30	5.81
Others	-	1.88	1.20

* Incomplete imaging

All classifications are rated as optimal, according to Kappa statistics, as observed in Table 10 (LANDIS; KOCH, 1977).

Table 10 – Values of Kappa and Accuracy for the classification of Pinheiros subdivision

Assessment	2002 (%)	2008 (%)
Kappa	92.82	82.22
Accuracy	95.40	93.27

The classes were distributed in the same groups already specified for the analyses of other subdivisions. We found the following UFI values (Table 11):

Table 11 – UFI for Pinheiros subdivision

Period	UFI
2002	0.385234
2008	0.524980

The site of the subdivision of Pinheiros showed the highest indexes of urban forest, and in the years between 2002 and 2008, there was an increase of the UFI. As observed in the field study of the site, this site was more afforested than the others, which was corroborated by the UFI values.

In comparison to the study conducted by Silva Filho et al. (2005), the site of the subdivision of Pinheiros had higher UFI than four of the nine neighborhoods studied in the Piracicaba city (Jardim Monumento, Centro, Cidade Alta and São Dimas).

CONCLUSIONS

The use of the methods developed in this study allowed to perform quantitative analysis of urban afforestation of the study site. The use of geoprocessing and remote sensing allowed to obtain physical data of the urban environment of the city of São Paulo, and the Linear Stepwise algorithm showed the best results. However, the treatment and processing of input data are of extreme importance to ensure results compatible with the site reality, besides the creation of good-quality treatment for the supervised automatic classification.

The subdivision of Pinheiros showed better UFI for urban afforestation, mainly when compared with the subdivisions of Mooca and Sé, and this index was of great use to analyze a relation between permeable and impermeable elements found in a region and to monitor changes in the site in different years.

ACKNOWLEDGEMENTS

The authors wish to thank the Foundation for Research Support of the State of São Paulo (FAPESP) for the financial support.

REFERENCES

ALVAREZ, C.E.; PENTEADO, H.M. Corredores verdes urbanos: estudo da viabilidade de conexão das áreas verdes de Vitória. In: ENCONTRO NACIONAL DE ENSINO DE PAISAGISMO EM ESCOLAS DE ARQUITETURA E URBANISMO NO BRASIL, 8, 2006, São Paulo. **Anais**... Vitória: UFES. p. 1-12.

BRAGA, R. Região e gestão metropolitana no final do século XX: uma análise do caso paulista (limitações e avanços). In: SIMPÓSIO NACIONAL DE GEOGRAFIA URBANA, 6, 1999, PRESIDENTE PRUDENTE. **Anais...** Presidente Prudente: AGB, 1999. p. 320-325.

BOLAFFI, G. Urban planning in Brazil: past experience, current trends. **Habitat International**, Oxford, v. 16, n. 2, p. 99-111, 1992.

CENTENO, J.A.S.; RIBEIRO, S.R.A.R. Um método simplificado de fusão de imagens. In: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 13, 2007, Florianópolis. **Anais...** São José dos Campos: INPE, 2007. p. 5667-5673.

CIDADE DE SÃO PAULO. Disponível em: <http://www.cidadedesaopaulo.com/dados.asp>. Acesso em: 05 mar. 2008

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, IBGE. Disponível em: <http://www.ibge.gov.br/home/default.php>. Acesso em: 05 mar. 2008.

LANDIS, J.R.; KOCH, G.G. The measurement of observer agreement for categorical data. **Biometrics**, Washington v. 33, n.1, p. 159-174, 1977.

LILLESAND, T.M.; KIEFER, R.W.; CHIPMAN, J.W. **Remote sensing and image interpretation**. 5th ed. New York: John Wiley, 2004. 763 p.

MICROIMAGES, **TNTMIPS**: Image Classification. Linconl: MicroImages, 2006. 36p.

MOREIRA, M.A. **Fundamentos do sensoriamento remoto e metodologias de aplicação.** 3 ed. Viçosa: UFV, 2005. 320 p.

OUMA, Y.O.; TATEISHI, R. Urban-trees extraction from Quickbird imagery using multiscale spectex-filtering and non-parametric classification. **Photogrammetric Engineering and Remote Sensing**, Washington, v. 63, n. 3, p. 333-351, 2008.

PILOTTO, J. **Rede verde urbana**: um instrumento de gestão ecológica. 2003. 206 p. Tese (Doutorado em Engenharia de Produção) – Universidade Federal de Santa Catarina, Florianópolis, 2003.

PINHO, C.M.D.; RENNÓ, C.D.; KUX, H.J.H. Avaliação de técnicas de fusão aplicadas à imagem Quickbird. In: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 12, 2005, Goiânia. **Anais...** São José dos Campos: INPE, 2005. p. 4225-4232.

PORTAL DA PREFEITURA DA CIDADE DE SÃO PAULO. Disponível em: <http://www.capital.sp.gov.br/portalpmsp/homec.jsp>. Acesso em: 28 jan 2009.

QUICKBIRD. Disponível em <http://www.sat.cnpm.embrapa.br/satelite/quickbird.html>. Acesso em: 20 jun. 2008.

RIBEIRO, S.R.A.; CENTENO, J.A.S. Classificação do uso do solo utilizando redes neurais e o algoritmo MAXVER. In: SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 10, 2001. Foz do Iguaçu. **Anais...** São José dos Campos: INPE, 2001. p.1341-1348.

SILVA FILHO, D.F. **Aplicação de videografia aérea multiespectral na avaliação de floresta urbana.** 2004. 88 p. Tese (Doutorado em Agronomia), Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista "Júlio de Mesquita Filho", Jaboticabal, 2004.

SILVA FILHO, D.F.; PIVETTA, K.F.L.; COUTO, H.T.Z.; POLIZEL, J.L. Indicadores de floresta urbana a partir de imagens aéreas multiespectrais de alta resolução. **Scientia Forestalis**, Piracicaba, 67, p.88-100, 2005.

VALERIO, A.M.; SILVA, G.B.S.S.; KAMPEL, M.; STECH, J.L. Avaliação da classificação não supervisionada do uso do solo e tipos de água no reservatório de manso, MT. **Geografia: Ensino e Pesquisa**, Santa Maria, v. 12, n. 1, p. 4081-4095, 2008.

VRABEL, J. Multispectral imagery band sharpening study. **Photogrammetric Engineering and Remote Sensing**, Washington, v. 62, n. 9, p. 1075-1083, 1996.

WEBER, C; PETROPOULOU, C.; HIRSCH, J. Urban development in the Athens metropolitan area using remote sensing data with supervised analysis and GIS. **International Journal of Remote Sensing**, Amsterdan, v. 26, n. 4, p. 785-796, 2005.