MULTI-TEMPORAL ANALYSIS OF THE URBAN EXPANSION IN THE JUQUERIQUERE RIVER BASIN

***Vassiliki Terezinha Galvão Boulomytis*[1,2] *and Cláudia Durand Alves*[1]**
[1]*National Institute of Space Research – INPE, Remote Sensing Department – SERE, São José dos Campos, SP, Brazil;* [2] *Federal Institute of Education, Science and Technology of São Paulo - IFSP, Civil Construction and Natural Resources Departments, Caraguatatuba, SP, Brazil; e-mail:* likitgb@dsr.inpe.br; durand@dsr.inpe.br

ABSTRACT

The purpose of this work is to study the urban expansion around Juqueriquerê River, in Caraguatatuba, on the Northern Coastline of São Paulo State, Brazil, from 1986 to 2010. In this period the scenario of the urban development in the city, mainly in this area, has completely changed because of the massive investments on the deep petroleum and gas exploration (Pre-Salt).

The process of urbanization has been studied in the last years as it is associated to the main changes of the natural resources caused by the human activities. One of the ways to aid the territorial planning of the rural-urban transition areas is by verifying the trend of population growth, which stimulates directly the real estate speculation and the modification of the natural resources (Quevedo Neto; Lombardo; 2006). From 1991 to 2010, the population growth in Caraguatatuba was higher than the estimated one for the State of São Paulo and Brazil: initially with 52,878 inhabitants and in the end of the period, 99,540 inhabitants (IBGE, 2011).

The Juqueriquerê River is a very important river for nautical and fishery purposes in the city and it is located near the largest area of expansion proposed by the local governmental department of urban planning, which is being prepared at the present time. The purpose for the surrounding area of the Juqueriquerê River contemplates a variety of urban expansion zones, including the logistic and vertical housing zones. Thus, it is very important to evaluate the influence of the urbanization on the macro drainage of the area. The increase of impermeable areas may provide a higher runoff on the public ways and uncovered vegetation areas, causing the sediment transport and river silting. The remote sensing techniques have being frequently used to obtain information about the process of urbanization in a multi-temporal scale and also to provide tools for the modeling and monitoring of the land use in hydrographic basins. In the methodology proposed at this work, the urban and non-urban areas were obtained from the classification of GeoEye, Landsat TM5 and TM7 Images. The image classification and data integration was done by the use of Definiens and SPRING softwares. The thematic maps obtained were divided into the classes that mostly occurred in the area: urban, water, wood, grassland/crops, shadow, cloud and bare soil. The purpose was to achieve the mapping of the urbanized areas and study the land use and the population growth tendency. It was possible by the use of hybrid classification method using the association of manual and automatic approaches.

Keywords: *urbanization, land use, macro drainage, image classification, impermeable areas.*

INTRODUCTION

According to the UNFPA – United Nations Population Fund (2010), 50% of the world population lives in urban areas: in the most developed regions, the total is 75%, and in less developed ones, 45%. In Brazil, the urban population was about 35% in 1950 and in 2010, 84% (Figure 1) (IBGE, 2011). Deak (1999) affirms that, in this period, Brazil has been changed from an agricultural to a virtually urbanized country, while its urban population increased six times. The fast population growth constitutes one of the major problems for urban sprawl management.

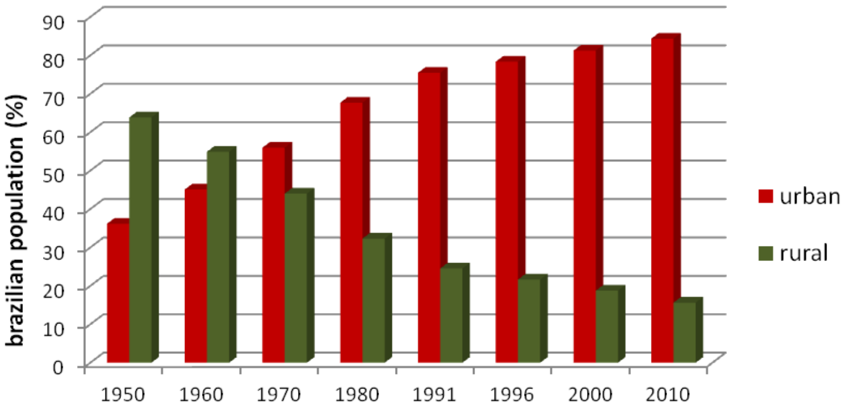

Figure 1 The Brazilian urban and rural population between 1950 and 2010.
Source: IBGE, 2011

The second part of the 20th century was remarkable for the acceleration of the urbanization process in Brazil, particularly in the State of São Paulo. Among the consequences of the process it is possible to notice: the formation of metropolitan regions; the verticalization and growth of the already urbanized areas; and, the urban expansion of the peripherical areas.

In the urbanized areas, Power et al. (2008) states that significant changes occur in the local natural resources, regarding their own ecosystem features, and also the surrounding ones. For Forattini (1991), during the development of the urban environment, the intense environmental modifications might affect the state of mind and the physiological state of the region inhabitants, influencing punctually or globally their quality of life.
The urbanization processes are very diversified, concerning both the spatial dispersion of low income groups (exemplified by the auto construction and occupation of irregular lots), and also the groups of medium and high income (exemplified by the construction in condos). These dynamics of occupation have strong social and environmental implications.

The prominent environmental impacts of this process might cause negative effects on the sanitation, water degradation, and an intensive deforestation (Torres et al., 2007).

In case there is a lack of planning, or legislation commitment, the urban expansion overlays or assembles social and environmental problems in some of the expansion areas. Poverty situations added to the degradation risks, such as, floods, debris and sediment flow, water pollution, river silting, illegal sewage flow, contact with diseases of hydro transmission, among others, are some of the impacts which characterize the social and environmental vulnerability of an area (Alves, 2006; Alves e Torres, 2006).

For Salinas Chaves (1998), in order to have a sustainable environment and the incorporation of a social and productive process, we depend on the use of more appropriate technologies to obtain: a social equality, a population growth balance, available natural resources and adequacy on the decision-making process.
Boulomytis (2011) states that the mathematical and computational methods have been widely applied for the study of complex system behaviors in modeling processes, in which, hypothesis are made and the forecast of the system stimulus under different circumstances is simulated. The computational simulation is a tool that occasion the model elaboration in a real situation in order to verify the effects for future, and sometimes, more complex events, even under different scenarios (Evora; Giorgetti, 1997).

In general, the urban modeling, including the new methods of expansion, such as the urban sprawl, however, present problems concerning the lack of knowledge and comprehension of the physical and social-economic features which contribute for a certain urban pattern and dynamics. For Peng et. al (2007), a reliable source for the acquisition of these information are the remote sensing data, which allows the continuous feedback and validation of urban models.

The remote sensing techniques and the GIS platforms have demonstrated a huge application on the urban area mapping and also on the urban expansion and land use modeling. By the use of these techniques, which provide a flexible environment for storing, processing and analyzing digital data from different sources, updated spatial data might be obtained and detailed with high temporal frequency, besides historical series. These data bring about a spatial and temporal vision of the urban growth and allow the provision of information about this environment such as land use and infra-structure. In addition, social and economic features might be deduced. It may aid the definition of public policies and the implementation of urban development strategies.

Multi-spectral, multi-temporal and multi-resolution remote sensing data are transformed by the use of new analytical methods, into important information for the comprehension and monitoring of the urban processes (Li and Weng, 2007). Li and Weng (2007) presented a methodology for the creation of a life quality index, by the use of a pilot area of the American city of Indianopolis, based on the integration of LANDSAT/ETM+ image data and the censitary information in a GIS environment. The environmental variables, such as, the amount of vegetation, impermeable surfaces and temperature were extracted from the images and censitary data. These authors verified that the vegetation has a high positive correlation with the income, residence cost and educational level, and a negative correlation with the temperature, impervious surfaces and high density of population or amount of residences. The work also demonstrated that the GIS environment might provide an effective platform for the integration of different data models from several sources, as remote sensing and censitary ones for the evaluation of the quality level in an urban environment.

Sparovek and Costa (2006) studied the interference of the urban evolution on the quantity, quality and distribution of vegetation cover, by analyzing the occupation dynamics and evolution of the urban sprawl in Piracicaba. It was done using aereal photograghs and GIS, in five different dates between the period of 1940 and 2000. In the vegetation survey they verified that the major portions of vegetation cover were found in the surroundings of the urban area, and highlighted the need of knowing and planning the peri-urban areas before they are modified by the urban structures.

In a study developed by Quevedo Neto and Lombardo (2006), the authors emphasize that the dynamics of the urban-rural transition area occurs regarding the pressure suffered by the urban environment, which stimulates the real estate speculation. It results on the modification of the environment, which is then characterized by a different land use mosaic. It is where conflicts, that should be very well-known, emerge for the constitution of a data base, which might allow the urban planning and the application of public policies.
With the advance of new sensors development, there was an improvement of the spatial, radiometric, spectral and temporal data resolutions. Thus, new possibilities for the orbital images use started to be applied for urban studies. Thoroughly, new methods had to be obtained to improve the data processing (Maktav et al., 2005), such as the automatization in the process of data interpretation, so that, a large amount of information might be produced in a systematic and objective way.

The traditional systems of automatic classification are based on the spectral information of the considered pixel in a single level of information. The intelligent systems of classification, as the object based one, allow the consideration of other attributes, besides the spectral ones to describe the classes, as context, shape and texture. Therefore, this type of approach becomes similar to a human cognitive system used in a visual interpretation classification. The advantage is to standardize the elements to be considered, reduce the subjectivity and increase the process speed, besides providing the possibility of reproducing the technique in other areas by different interpreters (Lang; Blaschke, 2003).

Several studies show the provision of better results in image classifications of urban studies comparing the object based approach with the traditional methods based on a pixel (Alves et al., 2010; Vieira, 2010; Alves et al., 2009; Antunes e Cortese 2007; Araújo, 2006; Yan et al., 2006; Pinho et al., 2005).

It is very noticeable that manual approaches are time consuming, coarse and subjective, and normally cannot be replicated in study areas with different features. Whereas, automatically generated data sets mostly ideal for practical use within real-time virtual environments because of the huge unstructured amount of data, therefore, common approaches most likely have a balance between human and computer efforts, called hybrid methods. Several studies have used the manual and automatic methods for maximizing the results obtained in the image classification (Huaifeng et al., 2010; Almeida et al., 2009; Durand et al., 2007; Habib et al., 2005; Udomhunsakul, 2004).

The object based approach supplies gains towards the precision and accuracy when compared to the traditional systems. Nevertheless, with the current available techniques there is still a need for the intervention of the interpreter through the manual edition in the end of the automatic classification process. This hybrid system of classification, with automatic and manual procedures, has been shown as a very efficient method in terms of human and computational precision and time spared (Lu et al., 2011), as used in this study.

According to Okida and Veneziani (1998) the fluvial and land use dynamics in the Juqueriquerê River Basin has been extensively modified. The result is the flood occurrence due to: the water table level, been very close to the ground surface; the presence of impervious surfaces; and, the river-bottom silting. So, the fragility of the area is translated to a range of diverse issues: the lack of riparian forests along the watercourses, increasing the runoff volume effect along the riverside; the natural river courses been rectified, causing the increase of the peak discharge; the inadequate occupation of constructions, beside the watercourses or over the wetlands and floodplains.

The sustainability of the development in the Juqueriquerê River Basin, in Caraguatatuba, State of São Paulo, Brazil, will thoroughly depend on the previous planning established for the area, implicating the significant need for comprehending how the expansion growth had already happened and also the effects of the current variables.

Finally, in this article, the scope was to promote the classification of the urban expansion, in order to understand how the modification phenomenon has already happened in the area. With this purpose in mind, it will be possible to comprehend how the development pressures caused by the Petroleum Exploration will affect the urbanization of the areas surrounding Juqueriquerê River, in order to evaluate the sustainability and fragility during the development of the area.

MATERIAL AND METHODS

The Juqueriquerê River Basin is the major one in the Northern Coastline of São Paulo State, Brazil, with 419.80 sq-km. It is divided into two municipalities: 341.60 sq-km in Caraguatatuba, which is the study area (Figure 2), and 78.20 sq-km in São Sebastião. Its waterway is a 4-km-long estuarine channel and is mostly used by small piers and docks. This basin is responsible for the major water discharge in the Northern Coastline of São Paulo State. It presents a significant potential for water contamination and environmental degradation due to the population growth, inefficiency regarding the sewage collection, presence of marines in vulnerable areas, lack of normalization for the use of fluvial transportation, presence of constructions in preservation areas.

In this study, the images used were: TM-Landsat, orbit/point 218/76, bands 3, 4 and 5, acquired on September 16th, 1986 and May 15th, 2005; ortorectified GEOEYE, acquired on April 30th, 2010. The applied softwares were Definiens v.7 and SPRING v.5.1.7.

Since the main purpose of the mappings was to identify the urban expansion, the 1986 image classification was initially done, so that only the increments of it could be considered at the following classifications. The thematic maps were elaborated from the TM-Landsat images at the Definiens software by the use of an object based classification. This method was based on two steps: segmentation and classification. At the first step, objects were created in different scales, according to the criteria of shape, color and homogeneity, all connected. At the second step, the objects became related by the definition of a class hierarchy (attribute heritage that describes a class) and semantic information (logical relationship structure among classes). In the image, an object represents an entity which might be individualized by the class attributes and properties of the original data (Definiens, 2006). These attributes do not only correspond to the spectral feature of the objects, but also to the topological relationships, texture, shape, and size, among others.

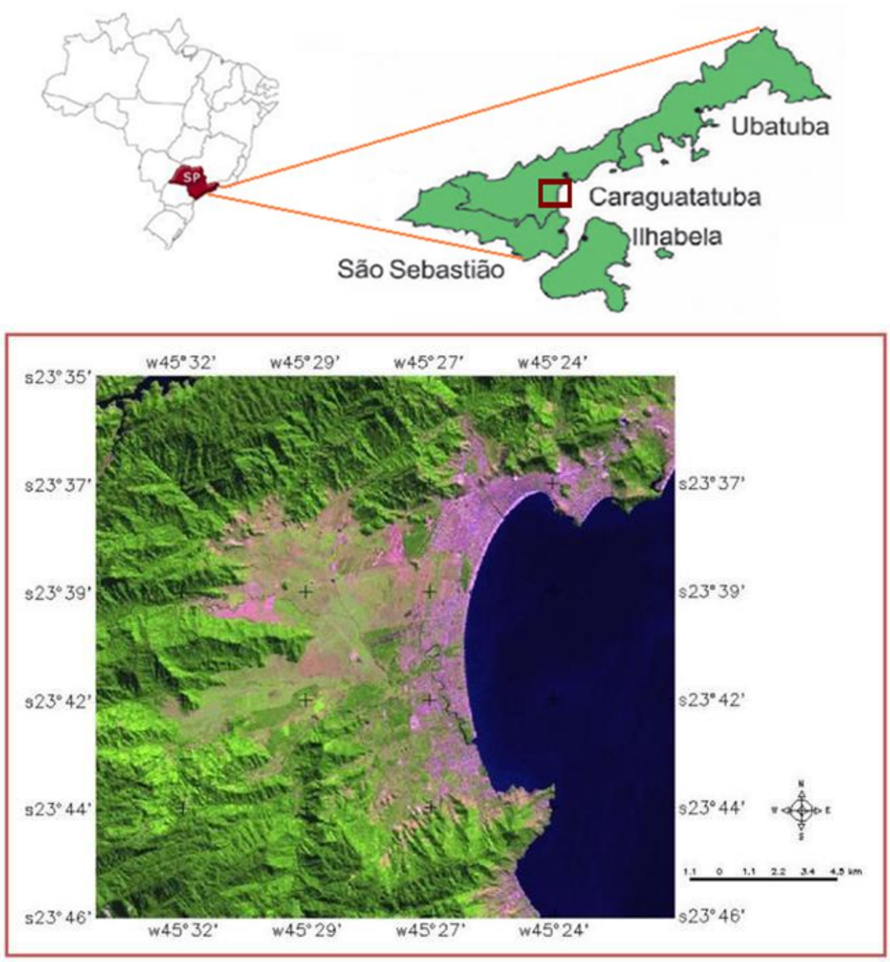

Figure 2 Location of the study area: Juqueriquerê River Basin, Caraguatatuba, SP, Brazil.

The segmentation is a fundamental step in this process, responsible for generating spectrally homogeneous segments which represent the inherent dimensions concerning the objects contained in the images (Blaschke; Hay, 2002). The purpose of this procedure is to find an ideal combination among the image objects and the geographical features of the real world objects.

At the Definiens software, the segmentation is done in two levels for a region-growing algorithm (multi-resolution segmentation), determined by a limier of similarity by the Weighted Average between color and shape, which are complementary, and its sum is always equal to one, and a scale factor. The parameter of color indicates the weight given to the spectral characteristics in detriment of the shape parameter. It is then subdivided into compactness/smoothness, with complementary concepts between each other, in which a high value of compactness conducts to smaller and compacted segments. These are opposite to the segments with more dendritic boundaries and with boundaries of non-fringed edges, when the higher value is given by its smoothness. The scale factor controls the maximum heterogeneity inherent to an object determined by an interpreter, so, the bigger the scale factor is, the bigger the generated segments will be (Kressler; Steinnocher, 2006). In this work, the used parameters were: scale (10), shape (0.1) and compactness (0.5), defined empirically based on the knowledge of the interpreter regarding the specific targets and images.

From the definition of classes, the class hierarchy was elaborated and used in all different dates (Figure 3). At the first level of the 1986 image segmentation, the separation of the vegetation and non-vegetation areas was done by the use of the Normalized Difference Vegetation Index (NDVI), as a classification attribute. At the second level of segmentation, the classification of different classes was done, in which texture attributes were used to separate the urbanized areas from the bare soil ones and spectral attributes (average between bands 3 and 5), to separate the water and shadow classes. For the separation of the clouds from the other classes, spectral attributes were used, among which, the negative values of NDVI and the maximum value of brightness.

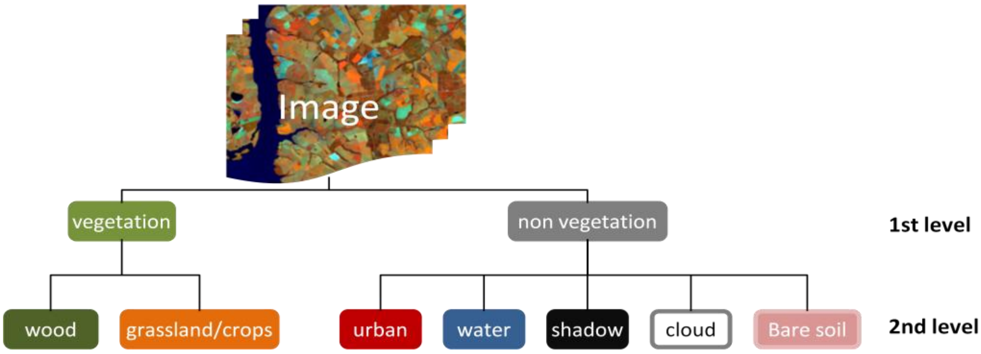

Figure 3: Class hierarchy used in the process of image classification.

In the classification process, the highest level of pertinence of an object regarding a class is used by the fuzzy logic (Chubey et. al, 2006). At Definiens v.7, the fuzzy pertinence function is elaborated by the selected attribute histograms. It is possible to have the qualification of an object, associated to a certain class, based on the level of pertinence given by imprecise limits.

In the classification of the case study, besides the spectral and texture attributes, relational attributes were also used, considering the same classes in different dates, among which, the object attributes, the relationship between classes, the global relationship and the logic operators (that may occur at the same class hierarchy level or at higher or lower ones). The group of attributes that describe each class is called descriptor. For the elaboration of the descriptors, samples were collected.

The classification of the 2000 Landsat images was based on the one obtained for the 1986 image, concerning the urbanized area, with the increment of the urbanization occurred only in that period. The same procedure was adopted for the 2005 image classification, regarding the results obtained for the 2000 one. For the classification of the 2010 high resolution image, it was not possible to apply the same procedure (the automatic object based classification) due to the limitations of time and hardware. Classifications using this technique have their complexity increased due to the elevate number of pixels that compose a single target in high spatial resolution images. Thus, it was chosen to classify the increment of the urban areas of the 2010 image by the use of visual interpretation and manual classification.

The validation of the image classification was done by the collection of random and stratified groups of samples. It was based on the visual interpretation of the images and the interpreter's knowledge of the area, and also on the pre-existing topographic maps and charts.

RESULTS AND DISCUSSION

In the object based classification, it was possible to verify that there was confusion between the classes representing some of the urbanized and bare soil areas, mainly in the mountainous region (commission errors). For these areas, the use of the texture attribute may reduce, but not completely eliminate the confusion between these two classes. The commission errors of urban classes occur in bare soil areas due to the transition use of new lots and industrial areas under implantation. However, the classification results considering their Kappa Index were: reasonable for the classification of the 1986 image (k=0.78) and excellent for the 2000 (k=0.81) and the 2005 (k=0.84) images (Congalton and Green, 1998).

Thematic maps were obtained from the classification of the 1986, 2000, 2005 and 2010 images (Figure 4). The urban expansion was observed in detriment of the increase rate in the urban areas of all the studied periods: 48% (1986 to 2000), 8.25% (2000 to 2005) and 10.80% (2005 to 2010). The relative growth rate for each period was 3.42% (1986 to 2000), 1.65% (2000 to 2005) and 2.16% (2005 to 2010), showing that it occurred mostly in the first and last periods.

There was a dispersion of the urban areas with the presence of isolated agglomerations in 2010, over the grasslands and crops. A successive increase in the urban area occurred down Juqueriquerê River to its mouth, from 1986 to 2010. In the last period, the small portions of remaining vegetation were drastically reduced and replaced by urbanized areas.

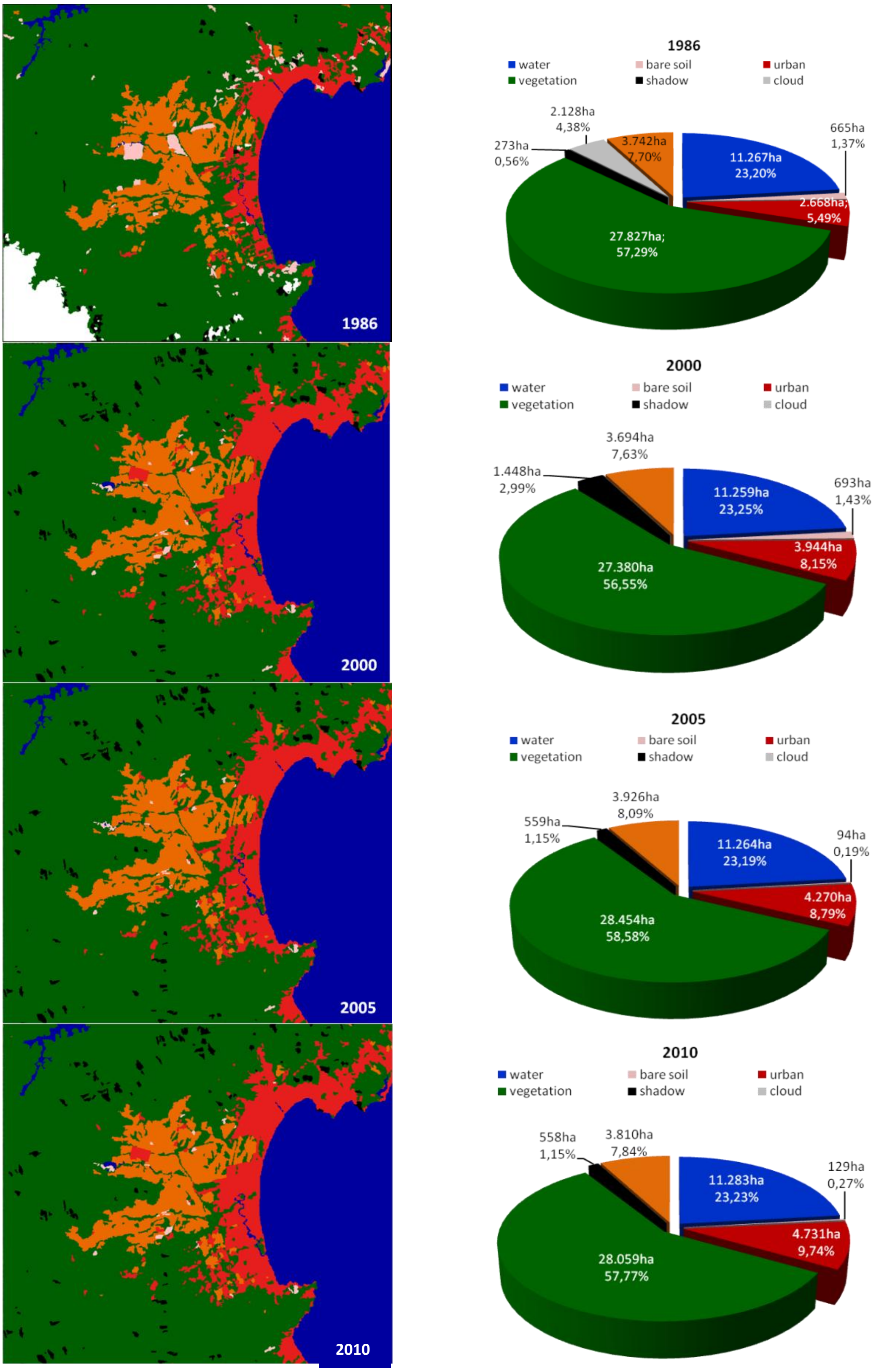

Figure 4 Thematic mapping and classification areas of the 1986, 2000, 2005 and 2010 images.

In the whole municipal area of Caraguatatuba, the increase in the percentage of the urbanized area (77%) was lower than the observed for the city´s urban population (191%) (IBGE, 2011) between the 80s and 2010. The highest relative growth rates of population and urbanized area occurred in the 90s, with higher rates for the urban population (Figure 5), which indicates a trend towards concentration of urban population, or an increased population density in the city.

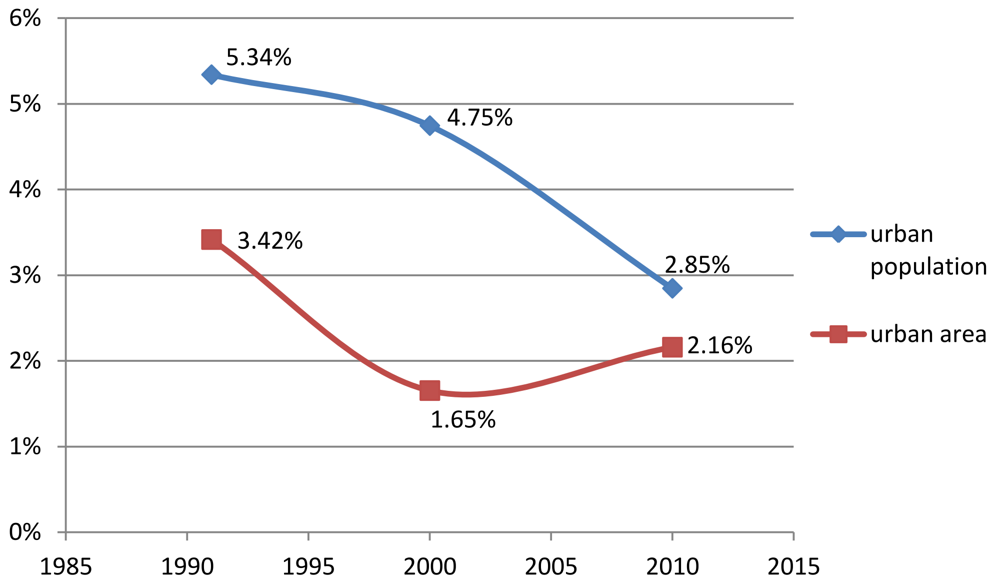

Figure 5 Relative growth rates of urban population and urbanized area of the City of Caraguatatuba, SP, Brazil.

As it can be seen in Figure 5, in the last decade, the relative rates of growth of urban population and urban area have opposite trends, approaching its values. Although in 2010 the relative rate of growth of urban population was slightly higher than in the urbanized area, this trend of convergence between the rates may indicate the occurrence of a process of dispersion of the population, or reduction in population density in relation to what had been observed until the last decade of the 20th century. This corroborates the studies that indicate a change in the pattern of land use in several Brazilian cities, characterized by dispersed urbanization.

Because of that, it is necessary to develop a coherent management plan, mainly in the regions with fragments of fragility and a prominent risk of water degradation. This is the situation of the Juqueriquerê River Basin, where there is a considerable inefficiency in the existing sewage collection, occupation in floodplains and wetlands, non-organized occupation of marines and infra-structure and increase in the peak discharge due to the rectification of the natural river channels up river to its source.

CONCLUSION

The methodology used for classifying the available images contributed for the analysis of the urban expansion in the study area. The results indicated that by the end of the twentieth century there was a trend towards the concentration of population in the urbanized area, leading to an increased population density. In the last decade this trend has reversed, with a trend towards the urbanization of the city of Caraguatatuba dispersed as a whole. But if we look at the specific areas such as the surrounding areas of Juqueriquerê River, the maps show the tendency of fulfilling the occupation of this region, in which the city is overlapping the remaining areas of vegetation.

This study revealed the fact that there is an emergent importance to develop a plan for the occupation of the new areas, but also, to manage the already occupied ones.

As the surrounding area of the Juqueriquerê River is the major one contemplated in the City Master Plan of the City of Caraguatatuba (being developed and discussed at the current time being), it is important to know how the area has already been modified. It is the only possible and logical way of preventing that the vulnerable areas become occupied without public policies to manage its adequacy.

REFERENCES

ALMEIDA, C. M.; SOUZA, I. M.; ALVES, C. D.; PINHO, C. M. D.; FEITOSA, R. Q. Métodos Cognitivos de Classificação Aplicados a Imagens QuickBird para a Detecção de Áreas Residenciais Homogêneas. **Revista Brasileira de Ciência do Solo**, v. 61, n. 1, p. 1-12, 2009. Disponível em: <http://www.rbc.ufrj.br/_2009/61_1_01.htm>.

ALVES, C.D., FLORENZANO, T. G., PEREIRA, M. N.. Mapeamento de áreas urbanizadas com imagens Landsat e classificação baseada em objeto. **Revista Brasileira de Cartografia,** v. 62, n. 2, p. 189-198, jun. 2010. Disponível em: <http://urlib.net/J8LNKAN8RW/38JE6T8>.

ALVES, C.D., PEREIRA, M. N. ; FLORENZANO, T. G. ; SOUZA, I. M. E. . Análise orientada a objeto no mapeamento de áreas urbanas com imagens Landsat. **Boletim de Ciências Geodésicas**, v. 15, p. 120-141, 2009.

ALVES, H. P. F. Vulnerabilidade socioambiental na metrópole paulistana: uma análise sociodemográfica das situações de sobreposição espacial de problemas e riscos sociais e ambientais. **Revista Brasileira de Estudos de População**, São Paulo, v. 23, n. 1, p. 43-59, jan./jun. 2006.

ANTUNES, A., F., B.; CORTESE, S., C. Determinação de áreas de ocupação irregulares por meio de análise orientada a objeto. In: Simpósio Brasileiro de Sensoriamento Remoto, 13, 2007, Florianópolis, SC, **Anais...** São José dos Campos: INPE, 2007. p. 481-487. ISBN 978-85-17-00031-7.

ARAÚJO, E. H. G. **Análise multitemporal de cenas do satélite QuickBird usando um novo paradigma de classificação de imagens e inferências espaciais. Estudo de caso: Belo Horizonte, MG**. 2006. 175 p. (INPE-13956-TDI/1062). Dissertação (Mestrado em Sensoriamento Remoto) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos. 2006.

BLASCHKE, T.; HAY, G. **Object-oriented image analysis and scale-space: theory and methods for modeling and evaluating multiscale landscape structure**. Jan., 2002. Disponível em: <www.definiens.com/publications.pdf>.

BOULOMYTIS, V. T. G. Modelagem e simulação no âmbito da hidrologia. **Revista Agrogeoambiental**, v. 3, n. 1, p.27-34, 2011.

CHUBEY, M.S.; FRANKLIN, E.; WULDER, M.A. Object – Based Analysis of Ikonos -2 Imagery for Extraction of Forest Inventory Parameters. **Photogrammetric Engineering & Remote Sensing**, v. 72, n.4, p .383-394, apr. 2006.

CONGALTON, R. G. E GREEN, K. **Assessing the Accuracy of Remotely Sensed Data: Principles and Practices**, New York: Lewis Publishers, p.137, 1998.

DEÁK, C. Uma interpretação histórica da teoria de renda. Revista de Desenvolvimento Urbano e Regional. v. 2, n.1, p. 41-57. Sinopses 18, p. 26-30, 1999.

DEFINIENS. **Definiens professional 5:** reference book. Munich: Definiens (The Imaging Intelligence Company), 122 p., 2006.

DURAND, C.; PEREIRA, M. N.; MOREIRA, J. C.; FREITAS, C. C. Análise da Correlação entre População e Área (km2) visando a Inferência Populacional por meio do uso de Imagens Orbitais/Analysis of the correlation between population and urban area aiming at the population inference using orbital images. **Geografia**, v. 16, n. 2, p. 113-142, jul.-dez. 2007. Disponível em: <http://urlib.net/sid.inpe.br/mtc-m18/2010/09.15.12.51>.

EVORA, J. E. M.; GIORGETTI, M. F. Simulação de processos de engenharia sanitária e Ambiental utilizando o programa SAAM for windows. In: CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA E AMBIENTAL, 19, 1997, Fóz do Iguaçu. **Anais...** Fóz do Iguaçu: ABES, 1997. p. 1949-1958.

FORATTINI, O. P. (1991) Qualidade de vida e meio urbano. A cidade de São Paulo, Brasil. **Revista Saúde Pública,** v. 25, n. 2, p. 75-86.

HABIB, A.F., KIM, C.J., KIM, E.M.. Linear features for semi-automatic registration and change detection of multi-source imagery. **Proceedings…** IEEE International Geoscience and Remote Sensing Symposium IGARSS, v. 3, p. 2117-2120, 2005. DOI: 10.1109/IGARSS.2005.1526435.

HUAIFENG, W., YONGMEI, Z., XI, C. 2010), Technology of Change Detection for the Semi-automatic Rapid Evaluation of Seismic Damage of Buildings. International Conference on Intelligent System Design and Engineering Application (ISDEA), v. 2, p. 548-552, 2010. DOI: 10.1109/ISDEA.2010.398.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE. **Sistema IBGE de recuperação automática (SIDRA)**, 2011. Available in: http://www.sidra.ibge.gov.br/bda/acervo/acervo2.asp?e=v&p=CA&z=t&o=11

KRESSLER, F. P.; STEINNOCHER, K. Image data and LIDAR – An ideal combination matched by object-oriented analysis. In: First International Conference on Object-based Image Analysis (OBIA 2006), 2006, Viena, Austria. **Proceedings**… Viena: ISPRS, 2006.

LANG, S. ; BLASCHKE, T. . Hierarchical object representation. comparative multi-scale mapping of anthropogenic and natural features. In: **International Archives of Photogrammetry and Remote Sensing**, vol. 24 (3/W8), pp 181-186, 2003.

LI, G.; WENG, Q. Measuring the Quality of Life in City of Indianópolis by Integration of Remote Sensing and Census Data. **International Journal of Remote Sensing and Census Data**., vol. 28, n. 1–2, p.249–267, jan. 2007.

LU, D., HETRICK, S. MORAN, E. Impervious surface mapping with Quickbird imagery. **International Journal of Remote Sensing**, v.32, n.9-10, p. 2519-2533, may 2011.

MAKTAV, D., JÜRGENS,C.;ERBEK.F.S. Remote sensing of uban areas. International Journal of Remote Sensing, v.26, n.4, p. 655-659, feb. 2005.

OKIDA, R., VENEZIANI, P. Sensoriamento Remoto como Alternativa no Estudo de Áreas de Inundação: um exemplo na região de Caraguatatuba (SP). In: 9th Simpósio Brasileiro de Sensoriamento Remoto, (SBSR 1998), 1998, Santos, SP, Brazil. **Anais..**, p. 425-429.

PENG, J.; WANG, Y.; YE, M.; WU, J.; ZHANG, Y. Effects of Land - Use Categorization on Landscape Metrics: A Case Study in Urban Landscape of Shenzhen, China. **International journal of Remote Sensing**, v. 28, n. 21-22, p. 4877–4895, nov. 2007.

PINHO, C. M. D; FEITOSA, F. F. e KUX, H.; Classificação automática de cobertura do solo urbano em imagem IKONOS: Comparação entre a abordagem pixel-a-pixel e orientada a objetos. In: Simpósio Brasileiro de Sensoriamento Remoto. (SBSR) 12, 2005. **Anais...** São José dos Campos: INPE, 2005. Artigos p. 4217 - 4224. CD-ROM. ISBN 85-17- 00018-8.

POWELL, S.L., COEHN, W.B., YANG, Z., PIERCE, J.D., ALBERTI, M. Quantification of impervious surface in the Snohomish Water Resources Inventory Area of western Washington from 1972-2006. Remote Sensing of Environment. V. 112, p. 1895-1908, 2008.

QUEVEDO NETO, P. S.; Lombardo, M. A. Dinâmica e Qualidade da Paisagem na Área de Transição Urbano – Rural. **Geografia**, Rio Claro, v.31, n. 2, p.257 – 268, mai/ago. 2006.

SALINAS CHÁVES, E. El desarrollo sustentable desde la ecologia del paisaje. In: Salinas Cháves, Eduardo; Middleton, John. (Orgs.) **La ecologia del paisaje como base para el desarrollo sustentable em América Latina**, 1998. Available in: http://www.brocku.ca/epi/lebk/lebk.html.

SPAROVEK, G.; COSTA, F.P.da S. Evolução da cobertura vegetal da cidade de Piracicaba – SP (1940 – 2000). **Geografia**, Rio Claro, v.31, n. 2, p.331 – 336, mai/ago. 2006.

TORRES, H. G., ALVES, H. P. F. e OLIVEIRA, M. A. Expansão Urbana, Mercado Imobiliário e Degradação Ambiental em São Paulo. In: HOGAN, D. J. (Org.). **Dinâmica populacional e mudança ambiental: cenários para o desenvolvimento brasileiro**. Campinas: Núcleo de Estudos de População - NEPO/UNICAMP, 2007. ISBN 987-85-88258-09-9

UDOMHUNSAKUL , S. Semi-automatic road detection from satellite imagery. International Conference on Image Processing, v. 3, p. 1723-1726, 2004. DOI: 10.1109/ICIP.2004.1421405.

UNFPA – United Nations Population Fund. **Relatório sobre a Situação da População Mundial 2010 - Do conflito e crise à renovação:gerações da mudança.** New York:UNFPA, p.116, 2010.

VIEIRA, M. A. **Análise de imagem orientada a objeto e mineração de dados aplicadas ao mapeamento da cultura da cana-de-açúcar**. 2010. 110 p. (sid.inpe.br/mtc-m19@80/2010/04.08.17.43-TDI). Dissertação (Mestrado em Sensoriamento Remoto) - Instituto Nacional de Pesquisas Espaciais, São José dos Campos, 2010. Disponível em: <http://urlib.net/8JMKD3MGP7W/37A6SQ8>. Acesso em: 29 abr. 2011.

YAN, G.; MAS, J. –F.; MAATHUIS, B.H.P.; XIANGMIN, Z.; VAN DISK, P. M. Comparison of pixel–based and object oriented image classification approach – a case study in a coal fire area, Wuda China. **International Journal of Remote Sensing**, vol. 27, No.18 – 20, September – October 2006, pp.4039 – 4055.