

# THE INCREASE OF ARTIFICIAL LAKES AS A RESULT OF SAND MINING ACTIVITIES, IN THE PARAÍBA DO SUL RIVER VALLEY BASIN, SÃO PAULO STATE, BRAZIL

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## SUMMARY:

Object-oriented paradigm is an alternative to the conventional “pixel-to-pixel” image classifiers, since it take into account the topologic and geometric information relating to the objects. The area being studied by this paper corresponds to the part of the Paraíba do Sul River basin located within São Paulo state, on a regional scale, and to the municipality of Tremembé, on a local scale. This region is notable for the large quantities of sand it produces for the construction industry - mostly for the Metropolitan Region of São Paulo. This economic activity has been having a negative impact on the environment in the form of artificial lakes. This study is committed to exploring the object-based image analysis in the mapping of the use and occupancy of the land, with an emphasis on the monitoring of the lakes arising from the sand mining process, using Landsat 5-TM images of the entire basin, corresponding to UGRHI number 2 - Paraíba do Sul River Basin - taken over three different decades (1986, 1996 and 2007) and Ikonos-2 images from the municipality of Tremembé. The DEFINIENS (v. 7.5), ENVI (v. 4.6.1) and ArcGis (v. 9.3.1) software programs were used in the pre-processing, segmentation, classification, evaluation of classification, data analysis and layout preparation procedures.

## 1. INTRODUCTION AND OBJECTIVES

### 1.1 The insertion of the São Paulo area of the Paraíba do Sul River Basin in the context of mining

The Paraíba do Sul Valley is the main connection region between São Paulo, Rio de Janeiro and Minas Gerais, the three Brazilian states in which 40% of the population and practically 50% of the country's GDP (IBGE - The Brazilian Institute of Geography and Statistics – 2009 estimate) is concentrated. This scenario is the result of an historical process which returns to the era of colonization, when the use and occupation of Brazilian land was guided by large economic cycles, in keeping with the interests of the metropolis. Amidst the ups and downs of the economic cycles, the infrastructure for the installation of the industrial, commercial and economic processes ended up being concentrated principally in the southeast of the country.

Mining is considered to be the main subsidiary activity in the processes of urbanization and economic growth, although society has had a negative image produced for it around this sector, due to the great impact it has had on the natural environment and the lack of actions that could have been implemented for the minimization of these effects.

The real picture could not be more different, since the activities demanded by the Brazilian urbanization process, as well as the advent of this urbanization itself, have not been conducted with any sort of planning, nor with even the slightest hint of sustainable environmental thought. The burden this has caused for us today, in a manner which is more and more acute, challenges those active in the diverse areas of government and civil society to search for immediate solutions to the issues arising from the destructive processes of use and occupation of the land which have historically been in place throughout Brazil's vast territory.

Within this context, pressures arising from urban growth and the paralyzing of extraction at sand beds located near the metropolis of São Paulo, were decisive factors for the insertion, at the beginning of the 1950s, of the portion of the Paraíba do Sul Valley located in São Paulo state as a supply pole for sand to be used in civil construction. Currently, according to data held by ANEPAC (National Association of Aggregate Producers for Civil Construction), this area is the largest sand supplier for the São Paulo metropolitan region.

### 1.2 Environmental damage and the actions of the São Paulo State Secretariat for the Environment

Sausen (1988) identified the extraction of sand as the principal activity contributing to the most accentuated changes in the form of the River Paraíba channel, due to the deepening and widening of such channel between 1953 and 1984, along the stretch between Jacaréi and Caçapava.

Researchers consider the extraction of sand from underwater troughs as the activity which causes most damage to the environment due to the difficulty in recuperation of the damaged areas. According to Reis (2005), this type of extraction is implemented due to the proximity of the water table, using a dredge under the boat equipped with centrifugal pumps. In figure 1, a mining trough area can be seen in the municipality of Tremembé (SP).

The abovementioned author, by means of the construction of a geo-referenced database, evaluated the evolution of the degree of interference of the sand extraction activities on the alluvial Flood Plains of the Paraíba Valley, on the stretch between Jacaréi and Pindamonhangaba, between the years 1993 and 2003, through a calculation of the volume of water evaporating into the atmosphere from the troughs and concluded that the increase in this volume occurred proportionally to the increase in the number of lakes.



Fig. 1- Example of an active mining trough in the municipality of Tremembé (SP).

In the mid-1990s, the São Paulo State Secretariat for the Environment started actions in relation to this scenario, through the creation of a working group (Resolution 35/96) which brought together and organized a number of organizations under its auspices, in search of a means of controlling and planning this mining activity. The pilot area for the establishment of the actions was established in keeping with the intensity of the sand extraction process between the cities of Jacaré and Pindamonhangaba. The investigation into the sand-supplying potential in the Paraíba do Sul Valley should be highlighted, this having been undertaken by the Geological Institute (SÃO PAULO, 1995), and which oriented the regulation (Resolution SMA-42 of 16/09/1996) and the planning of the enterprises (Resolution SMA 28/99).

### 1.3 - Environmental monitoring and remote sensing

Environmental monitoring requirements, conservation goals, spatial planning enforcement, or ecosystem-oriented natural resources management, to name just a few drivers, lend considerable urgency to the development of operational solutions that can extract tangible information from remote sensing data. (BLASCHKE, 2010, p. 2)

By means of the process of image classification it is expected that information shall be extracted which is characterized in keeping with the properties of the objects and the standards of which they are constructed. Basically, the paradigms involved in the classification of images are divided into the divisions of “pixel to pixel” or into the “object-oriented”. In the first case, only the spectral information of each pixel is used for the identification of homogenous regions and the separation of the classes will depend on the Employed-Statistical Method (Closest Neighbour, Minimum Distance, Maximum Verisimilitude, Parallelepiped) or the Deterministic Method (Function and Network). (CROSTA, 1992).

As concerns the classifiers “oriented to objects”, as well as spectral information on each “pixel”, the spatial information which involves the topological relation to its neighbours is used. The border information is initially used to separate regions whilst the spatial and spectral properties will unite areas of the same texture (INPE, 2010).

When the issue of the relevancy of the classes is approached, as much in the statistical method as in the deterministic method,

the employment of Boolean logic based on probability is more common. However, the employment of fuzzy logic, which is based upon the variation of uncertainty, increases as a result of the great internal variability of the classes, on account of the increase in the spatial resolution of the orbital images, above all in intra-urban environments (ANTUNES, 2003).

### 1.4- Objectives

The central objective of this paper is the analysis of the use and occupation of the land, with an emphasis on monitoring the mining troughs, by means of geographic object-based analysis of orbital images, as much on a regional scale as on a local one. On the regional scale, the area of study corresponded to the São Paulo state part of the Paraíba do Sul River Basin – Water Resources Management Unit (UGRHI-2). As for the local scale, the focus fell upon the municipality of Tremembé (SP), as a form of subsidizing the hydro-climatic and hydro-geological studies (Proc. Fapesp 2008/05400-9), which were developed in a pilot area named “Porto de Areia Paraiso”, located on the flatlands beside the river, to the east of the municipality, and which investigate the interference between the sand extraction troughs and the aquifer.

The São Paulo state part of the Paraíba do Sul River Basin, is situated in the southeast of the state of São Paulo and the municipality of Tremembé is located in the Upper-Middle Paraíba River Valley. (fig. 2).

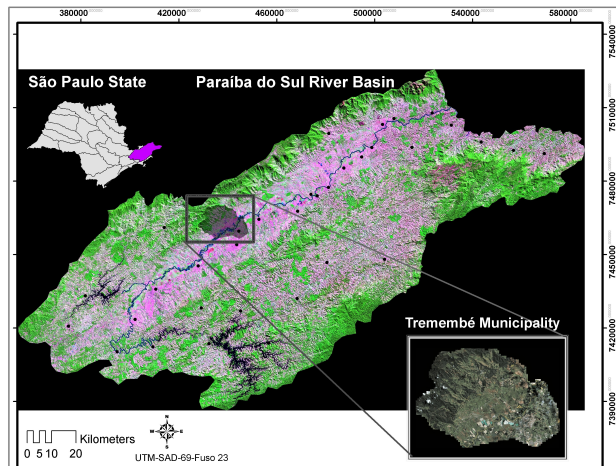


Fig. 2 - Location of the areas, in the regional (Landsat 5-TM Mosaic), and local scales (Ikonos 2 Mosaic).

Investigations using satellite images to monitor the artificial lakes of mining are common in this region, although the algorithms utilized in these investigations generally address the “pixel to pixel” paradigm, whilst others simply use visual interpretation (SIMI et al., 2009). This paper however, is justified by the exploration of another paradigm in the classification of orbital images, the object-based image analysis.

### 1.5- Selected physiographical aspects of the area involved in the study

Figure 3 shows the map of the tectonic-stratigraphical units in the São Paulo state part of the Paraíba do Sul River Basin, which, in conjunction with external agents (above all the actions of the waters) condition the geomorphology, as well as in the use and occupancy of the Basin under discussion.

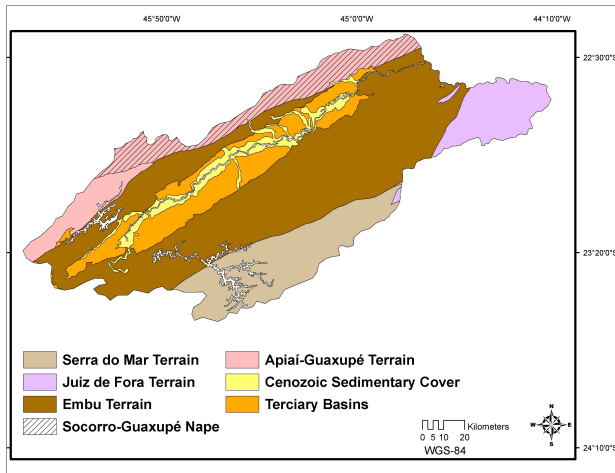


Fig. 3- Tectonic-stratigraphical units in the Paraíba do Sul River Basin, São Paulo. Fonte: CPRN (2006)

According to Almeida (1964), the Paraíba do Sul River Basin forms part of the territory of the Atlantic Plateau, in the zones which include:

- The Bocaina Plateau – located in the area of Juiz de Fora and the transition to the area of Embu. The altimetry reaches 2,000m, whilst the down slopes are superior to 30%, with fissures and fractures, within which are lodged the springs of the Paraíba River; the lithological composition consists of migmatites, granites and granitoids.
- The Paraitinga Plateau - made up of the area of the Serra do Mar and part of the area of Embu. From the Bocaina Plateau to the municipal limits of Guararema, the Paraitinga Plateau continues, upon which there is accentuated differential erosion, highly dissected forms of relief, declivity of 20% to 40% - as a result of the effects of the waters of the Paraitinga and Paraibuna Rivers. According to Almeida (1964, p. 26), this is an area consisting of around 6,000 km<sup>2</sup>, a structurally complex crystalline plateau, with sea relief from hills and extensive longitudinal mountain ranges (ENE).
- The mid-zone of the Paraíba River Valley – with the sub zones of the Cristalinos Hills and the Sedimentary Foothills – forming part of the areas with Cenozoic Sedimentary Cover and Tertiary Basins. It is made up of the stretch preceding the famous ‘elbow’ in the Paraíba do Sul which extends across the entire area of the spurs of the Mantiqueira and Bocaina mountain ranges. This is an elongated depression, with relief consisting of foothills and low hills which separate the Mantiqueira and Bocaina Plateaus (ALMEIDA, 1964, p. 30). Due to the physiological conditions, it is the most highly populated region in the Basin where the main economic activities have been developed.
- Serra da Mantiqueira, Western and Eastern sub zones and the Campos do Jordão Plateau – these areas occupy the Apiaí-Guaxupé and Nape Socorro-Guaxupé Areas. The Mantiqueira mountain range zone is an area of elevated scarps and relatively isolated hills. The elevations of around 2,000m and difference in levels of between 1,500m and 2,000m,

between the Crista da Mantiqueira and the Flood Plains of the Paraíba River Valley, provide this with the most abrupt relief in the State. Finally, the Campos do Jordão Plateau is a tectonically elevated area, composed of a complex crystalline structure, reaching 2,000m in altitude. There are long mountain ridges, oriented to ENE, which have been extremely cut through by ravines and where the difference in levels between the highest ridges and the depths of the valleys exceeds distances of 300m (Almeida, 1964, p. 39-40).

From the confluence of the Paraitinga and Paraibuna Rivers, the headwaters of which originate in the Bocaina mountain range, the abovementioned water course comes to be named the “Paraíba do Sul River” near to the municipality of Paraibuna. From Guararema on, the course of the river heads southwest, turns a bend, and continues in a north-easterly direction, which, according to Ab’Saber (1957), suggests a fluvial capture, a situation in which the old headwaters of the Tietê River have been annexed by the Paraíba River, such being favoured by the tectonic origin of its Flood Plains. (Fig. 4)



Fig. 4 – Guararema (SP). Illustration of the inversion of the Paraíba River, known as the “Elbow of the Paraíba do Sul River”, Photo: Ananias, F.C.W., EEAR, 2003, apud Reis (2005)

## 2. MATERIALS AND METHODOLOGY

### 2.1 Materials

For the regional scale analysis, orbital image data from the Landsat5 satellite’s TM sensor, which provides seven multi-spectral bands, were used. The fact that this satellite has been in operation since 1984 makes it possible for the undertaking of the temporal study of the evolution of the use and occupancy of the intended lands. The images (218/219) were acquired over three distinct decades (1986, 1996, 2007).

For the local scale analysis, high-resolution images were utilized, having been taken by the IKONOS II satellite in October 2006 and covering the entire municipality of Tremembé (SP); the images were provided by the local municipal authorities.

As far as the variable data is concerned, the delimitation of the Mining Zoning was employed, such having been established by the Secretariat for the Environment (Resolution SMA Nr. 28, de 22/09/99). Mining polygons from the National Department of Mineral Production (DNPM) were also used in the Mining

Concession, Concession Request and Licensing stages. As a thematic layering in the segmentation of the Ikonos 2 image, the drainage and hydrography vectors were utilized at the scale of 1:10.000 established by the IGC (Geography and Mapmaking Institute).

The programs 'ENVI, version 4.6.1', and 'Definiens, version 7.5' were used for processing the images. The 'ArcGis, version 9.3.1' was also used for treatment of the variable data and preparation of the layouts.

## 2.2 Methodology

**2.2.1 - Pre-processing:** the images from the TM-Landsat5 sensor were recorded, formed into a mosaic and re-cut to the dimension of the Paraíba do Sul River Basin – Water Resources Management Unit. The RGB bands of space were converted to HIS (Hue, Intensity, Saturation) space, and the main components were extracted. In the case of the image from the IKONOS-2 satellite, the same procedures were followed, with the exception of the registration, mosaic formation and re-cutting, which were already found to be available in relation to the municipality of Tremembé (SP).

The pre-processing stage is essential in the classification focusing on the object, since it allows one to make the information available for the study feasible through the extraction of derived images which will enable the identification of the areas of target interest on the surface.

**2.2.2- Segmentation:** classification oriented towards the object, part of the principle that the semantic information necessary for the interpretation of an image is not present in the pixel, but rather in its groupings – the objects – and in the relationships existing between them. Such objects arise from the segmentation process.

In this work, two segmentation algorithms were employed: the Multi-resolution Segmentation algorithm that locally minimizes the average heterogeneity of image objects for a given resolution of image objects, and the Spectral Difference Segmentation, which joins neighbouring objects according to the average intensity of the values. (DEFINIENS, 2007).

Through the Multi-Resolution Segmentation by means of the Definiens (v. 7.5) software, it is possible to create levels with differentiated scales which are connected in a hierarchical manner, as well as use thematic information (bitmap or variable) in the process of its composition.

In this segmentation process, parameters such as scale, layer weights and homogeneity criteria need to be defined by the analyst.

Three levels of segmentation were employed for the classification on the regional scale and five levels of segmentation for the classification on the local scale, where in the latter case, variable thematic layers of alignment and drainage (IGC, 1:10.000) were added.

### 2.2.3 - Classification:

In both the sets of images with different spatial resolutions, the classification object-oriented was utilized.

With Definiens (v. 7.5), there are two possibilities for classification: the 'Nearest Neighbour' rule and the 'Membership Function' rule. In the first case, there exists the process of selection of typical objects as representative examples. In the second, there is added the inclusion of concepts and knowledge for the definition of classification strategies – through the description of classes for example. It

was decided to combine the two techniques for the establishment of the strategy best suited to each class in each of the sets of data. In the structuring of the classes of different levels, the logic of group hierarchy, with semantic relations, was employed to the same extent as inheritance

**2.2.4 - Evaluation of the Classification:** The confusion matrix is a celebrated method in literature for evaluating the quality of the classification since it describes the accuracy of each class with their errors of commission and omission. From the confusion matrix the Kappa coefficient of conformity is calculated, this being based upon the difference between the conformity observed and the chance of conformity between the reference data and a random classification (Congalton and Green, 1999).

However, when fuzzy logic is employed, the same object may be associated with various classes at the same time with distinct degrees of relevance, leading to uncertainty in the classification, such which cannot be evaluated by the confusion matrix. In this sense, the software used makes a tool available for calculating the instability of the classification, in which the difference between the best and the second best class assignment is calculated as a percentage. The statistical output displays basic statistical operations (number of image objects, mean, standard deviation, minimum value and maximum value) performed on the best-to-second values per class. (DEFINIENS, v. 7.5)

## 3. RESULTS AND DISCUSSIONS

### 3.1 - The issue of the mining troughs

The publication of Resolution SMA Nr. 28, dated 22/09/99, prepares for the environmental zoning for sand mining in the sub-stretch of the Paraíba do Sul hydrographic basin, passing through the municipalities of Jacareí, São José dos Campos, Caçapava, Taubaté, Tremembé and Pindamonhangaba, by means of the definition of the following areas:

- I. Protection Zone - ZP;
- II. Mining Zone - ZM;
- III. Recuperation Zone - ZR;
- IV. Flood Plain Conservation Zone - ZCV.

The objective of the protection zone (ZP) is to protect the ecosystem formed by the Paraíba do Sul River, the remaining preserved vegetation and especially the vegetation associated with the abandoned stretches. The sand mining zone (ZM) is the area where it has been proven that mining activity can be developed in an economical manner. The recuperation zone (ZR) is made up of areas defined as being of priority concern for environmental recuperation, with the objective of making them compatible for urban and cattle breeding uses or preservation, depending upon the specific location. The Flood Plain conservation zone (ZCV) seeks to protect and conserve the aluvionar Flood Plains, guaranteeing the permeability of the earth and non-contamination of the waters, through uses compatible with their ecological function. In figure 5, the entire stretch of mining zoning can be observed, with the troughs identified in the image from 2007. (SÃO PAULO, SMA 28/99 Resolution)

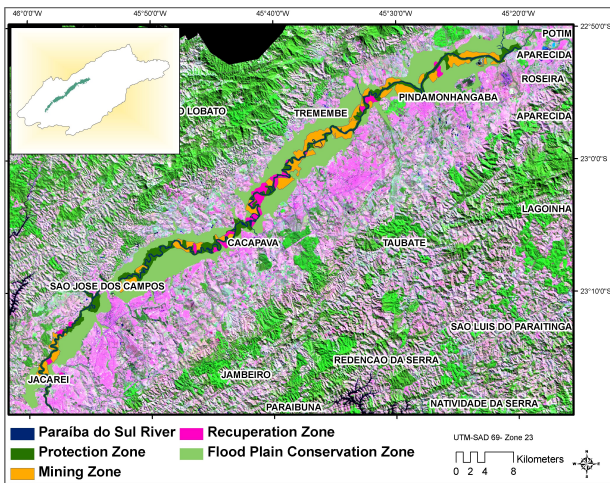


Fig. 5 – Illustration of the Mining Zoning, according to the SMA 28/99 Resolution.

In figure 6, from the results of the classification of the TM-Landat images, the increase in the number of sand mining troughs over the decades investigated - 1986, 1996 and 2007 - can be seen. The stretch of the Paraíba do Sul River which represented the most expressive increase in the number of artificial lakes was between the municipalities of Caçapava and Pindamonhangaba (Fig. 6). In the municipalities of Taubaté and Tremembé, the lakes took up a large part of the area named 'mining zone' and also advanced into the environmental recuperation zone.

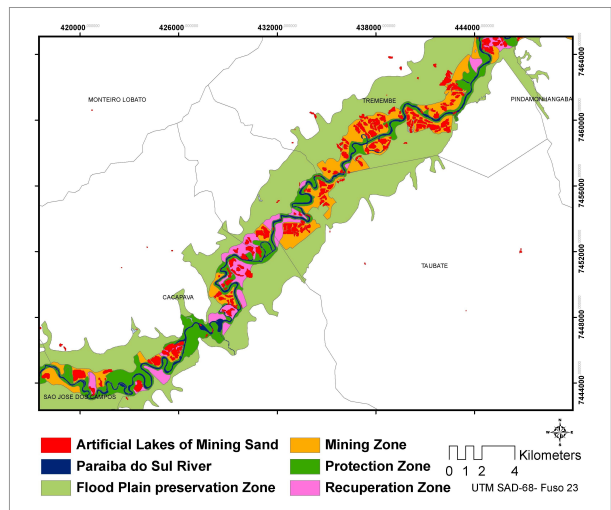
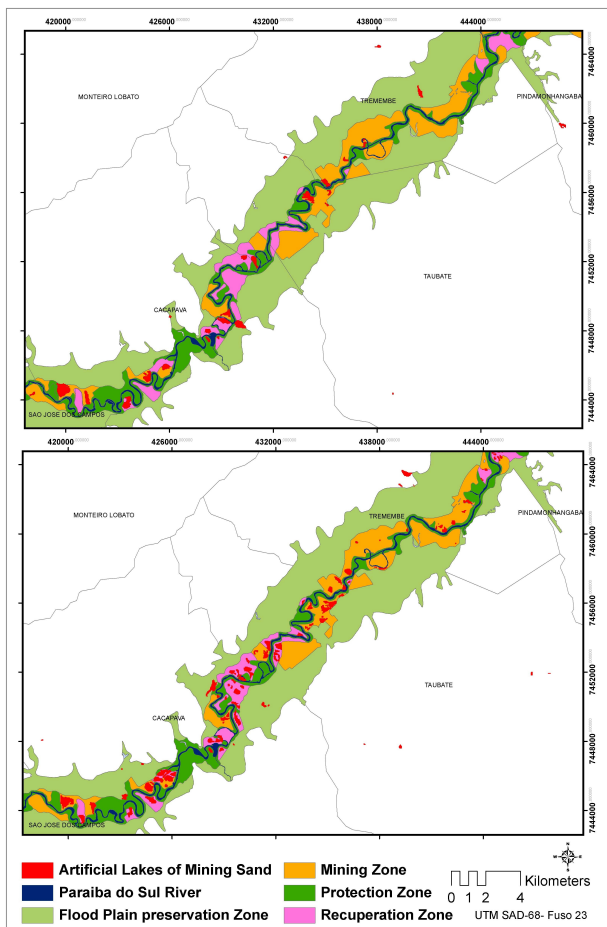


Fig 6 - Sand extraction lakes, extracted from Landsat5-TM-1986, 1996 e 2007, respectively; overlaying the Mining Zoning (1999).

The mining Authorization and Concession land use systems are titles which allow the utilization of a certain mineral resource. There is an intermediary title which is the Research Charter (Authorization System); the Final Research System having especially approved, with the qualification, quantification and economic feasibility of the mineral substance researched being included in the procedures for the obtaining of the system concession.

By looking at the overlapping of the mining polygons of clay and sand, obtained from the DNPM, and updated through until 13/04/2010, for the layer corresponding to the Mining Zoning (figure 7) and the troughs identified by the classification made in 2007, it can be seen that those of interest in terms of extraction go further in the direction of the Flood Plain Conservation Zone and Recuperation Zone, since there are various polygons in the mining and licensing phases in this area.

Another fact that deserves attention is the issue of the progression of sand and clay mining beyond the area which forms the Mining Zoning, as delimited by the Secretariat for the Environment. The municipalities of Roseira, Potim, Canas and Cachoeira Paulista, already present polygons in the stage of concession and request for mining, although in the classification from 2007, the lakes had still not been identified.



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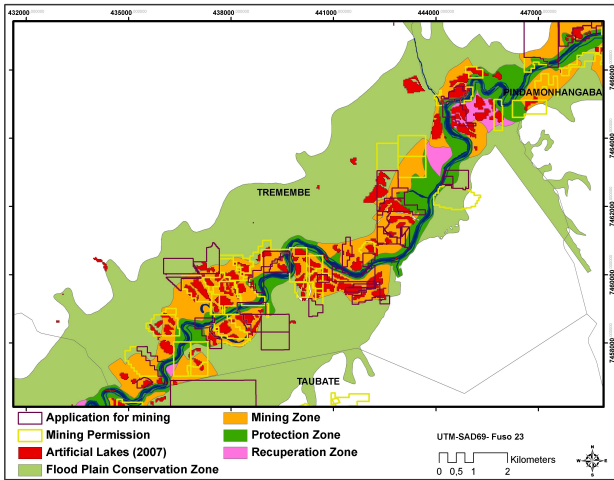


Fig.7 - Sand and clay mining polygons in the phases of mining concession (yellow) and request for mining or licensing (dark red-*sic.*), overlaid on the Mining Zoning (1999), on the stretch between Caçapava and Pindamonhangaba (SP).

In relation to the issue surrounding the recuperation of the area (ZR) through the planting of native species, by making a comparison of the classifications between 1986 and 2007 (fig. 8), initiatives with this in mind can be seen to have taken place, all be they rather timid. The stretch which shows most evidence of objects classified as dense vegetation near the mining area was between the municipalities of Jacareí and São José dos Campos.

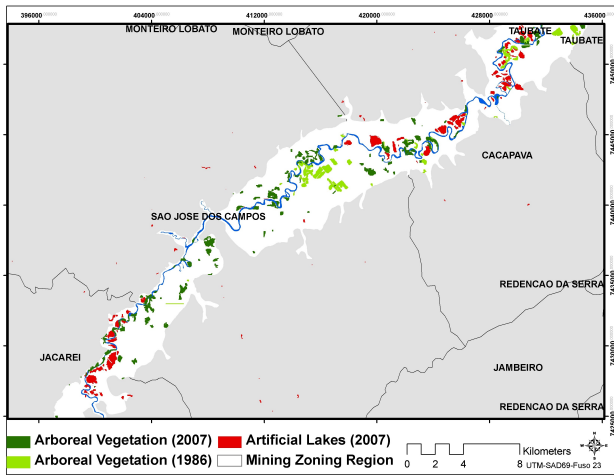


Fig. 8 - Arboreal vegetation (1986/1996), classified within the polygon corresponding to the Mining Zoning.

In the local analysis, by means of the classification of high-resolution images, in the municipality of Tremembé, the results of the demarcations of the troughs show themselves to be close to those obtained on the regional scale, with Landsat images depicting an increase in the area of the troughs in the recuperation zone identified in 1986 and a number of extrapolations to the Flood Plain conservation area, as can be seen in figure 9.

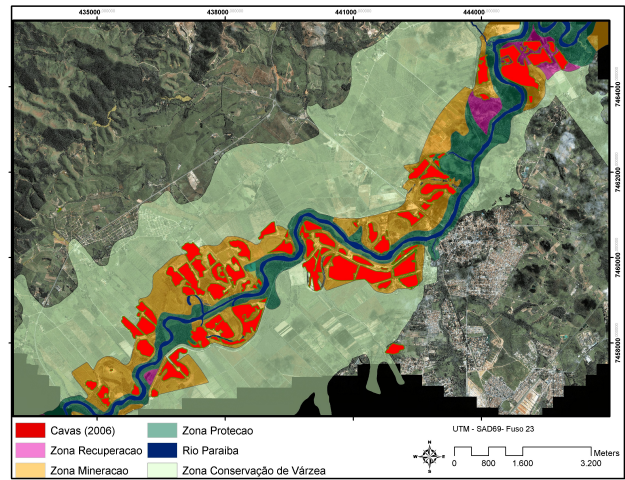


Fig. 9 - Identification of the troughs in the municipality of Tremembé using high-resolution images (Ikona-2).

### 3.2 - Evaluation of the Classification

The results of the confusion matrix, including the exactness of the producer, the user, the accuracy by class and the total, were clearly satisfactory for the sets of data, for both the high and the low resolution spectral, above 0.9. As for the stability of the classification of the objects, with the exception of the shadow class, the average was above 0.7, for the others; the trough class showed an average of 1, and is therefore considered to be stable.

## 4. FINAL CONSIDERATIONS

The sand mining activity in the São Paulo part of the Paraíba do Sul River Valley started in the 1950s in the area of the municipality of Jacareí in the south-western part of the basin. From there it advanced in the direction of São José dos Campos, Caçapava, Taubaté, Tremembé, Pindamonhangaba and Roseira.

- Remote sensing products together with techniques specially suited to classification and analysis are tools which should be adopted in environmental examination and monitoring by the various relevant organs, due to their high degree of efficiency in spatial analysis. Such measures need to be continuous, or in other words, their implementation should extend for more than four years, when changes the government, since the pressures for new areas of natural resources exploration are constant.
- The results of the object-based image analysis was satisfactory for both sets of different spatial resolution images, since the artificial troughs which are the result of the mining in the area – target subject of interest to us here – present various successive stages, from those currently in operation, passing through those which are inactive, and on to those covered by macrophyte vegetation with floating leaves. As well as this, the practice of mining which results in these lakes is developed in the midst of different land uses such as constructed urban environments, industrial areas, farmed agricultural land with marsh-type soils, exposed land and vestiges of vegetation, amongst others – factors which lead to problems in the separation of the classes when only the spectral informational is considered.
- Currently, any member of the population can obtain free access to spatial analysis software, in the form of

those with open access codes (GRASS, GVSIG) or those which are freely commercially available (SPRING-INPE), as well as orbital images (LANDSAT E CBERS).

- Development of research into the possibility of damage mitigation in the mining area and into the appropriation of new uses following the exploration is also urgent. Along these lines, this paper sought to generate subsidies for the hydro-climatic and hydro-geological investigations (Fapesp 2008/05400-9) being developed in the municipality of Tremembé, at the “Porto de Areia Paraiso”.
- At the location discussed, data collection equipment has already been installed - 8 piezometers and four wells each 4” in diameter have been constructed (Fig. 10 e 11). Infiltration tests, discharge tests, surface soil sample collections, SPT drilling and granulometric analyses in samples obtained during the SPT tests were also undertaken. The objective is the investigation of the interference of the sand extraction trenches in the aquifer.
- Finally, it is worth stressing that measures for the mitigation of deterioration will only meet with success when undertaken jointly by the various responsible parties, acting at the various levels of government and civil society, and, above all, with the involvement of the owners of the land.



Fig. 10- Activities in the installation of data collection equipments, in Tremembé municipality (SP).



Fig. 11- A piezometer installed in Tremembé municipality (SP)

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