MONITORING OF AGRICULTURAL LAND USE IN SÃO PAULO STATE – BRAZIL USING GEOTECHNOLOGY APPROACH

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Abstract

This study evaluated changes in agricultural land use on São Paulo state, Brazil, mapping and qualifying sugarcane expansion. The Percentage Change Index (PCi), calculated using official municipal census data was used to identify areas where sugarcane caused the main land use changes. The PCi provided the sugarcane percentage changes over 20 years of data. Detailed land cover maps for four municipalities with high PCi were created for two time periods (1990 and 2005), using satellite images. Results showed that sugarcane expansion over the 15 year period occurred mainly over pasture lands however, for one municipality, a high substitution of forest plantation areas was observed. Also, only one municipality showed a strong increase in short cycle crop agriculture, which also occurred over pasture areas. Results revealed that sugarcane expansion has a relationship with local economic aspects and the method used provided an important tool to define public policies and management decisions.

Key words

Geotechnology; Percentage change index; Sugarcane expansion hotspots.

Introduction

The ethanol represents 90% of total of biofuel consumed in the world. Particularly, sugarcane ethanol presents mitigation levels between 80 and 90% in CO_2 emissions during production, when compared to conventional gasoline, and also has competitive values over the final cost (IEA, 2007; Seabra et al. 2011).

The growth in demand for biofuels, particularly ethanol, led to the expansion of agricultural area previously occupied by other uses, also resulting in adverse effects such as impacts on food security and higher CO_2 emissions resulting from changes in land use. Brazil is the world's largest producer of ethanol derived from sugar cane, producing about 28 million cubic meters in 2010 (SPC, 2011), aided by environmental conditions and the reliable structure of production derived from government incentive policies. Since the 1970s, ethanol is used in the Brazilian transport sector as an alternative fuel, and in 1980 it became available as a replacement for gasoline as a substitute in a significant portion of the transportation sector (Walter & Cortez, 1999), representing 44% of total fuel consumed in 2006.

The recent rise for ethanol demands in the Brazilian and international markets has influenced land cover changes in the state of São Paulo, the largest sugarcane producer in Brazil, with 55% of the Brazilian production areas. This has led to an increase in sugarcane plantation in the state, especially due to favourable natural conditions (climate, soil) and the industrial infrastructure already in place.

According to FAO (2010) food prices reached the highest in 20 years, and among the several related factors to the price increase, a significant weight can be attributed to the reallocation of crop production for biofuel production (Graham-Rowe, 2011). The rapid changes in land cover also results in indirect impacts, such as replacement of areas of native vegetation (Graham-Rowe, 2011).

Land use / cover changes evaluations can be carried out by the use of geotechnologies (e.g. remote sensing, spatial analysis). However mapping and monitoring large areas still represents a challenge in regard to the resources needed to create accurate identification of several heterogeneous targets over time.

In this study our goal was improve the large area mapping and land cover change evaluation through remote sensing by using spatial analysis approach in a data driven process. Sugarcane expansion hotspots were first identified based in official census data, where land cover transitions were evaluated by detailed mapping. This provided an efficient and low cost methodology to monitor and evaluate the economic and environmental impacts of biofuel expansion.

Material and Methods

Sugarcane expansion over the 645 municipalities in São Paulo state was evaluated based on the municipal agriculture production data from the Brazilian Institute of Geography and Statistics (Produção Agrícola Municipal – IBGE), covering the period from 1990 to 2010.

Sugarcane area expansion or reduction was evaluated using the Percentage Change Index proposed by Berry (1993):

$$PCi = (P_{cur} – P_{pre}) / P_{pre} * 100$$

Where: P_{cur} is the sugarcane planted area in the current year and P_{pre} is the plated area in the previous time period.

The PCi was calculated for each municipality in the state considering all years. This allowed us to identify the municipalities with the highest land cover change due to sugarcane expansion and retraction on an annual basis. The PCi was also calculated considering three aggregated time periods: P1 (1990 – 1996); P2 (1997 – 2003) and P3 (2004 – 2010). This analysis allowed for the identification of sugarcane expansions and reductions occurring at larger time intervals. Municipalities that showed more than 100% increase in sugarcane area between periods P2 and P3 and also had more than 500 hectares of sugarcane planted in the year 2010 were identified as sugarcane expansion hotspots.

Land cover maps were generated for some of the hotspots municipalities, considering two time periods, 1990 and 2005, in order to evaluate the land cover types that were being substituted by sugarcane.

The land cover classification procedure was based on 30 meter resolution, Landsat 5 TM images, obtained from the Global Land Survey dataset (http://gls.umd.edu/). These are pre-processed images with the advantage of greatly simplifying the data manipulation needs (georeferencing, mosaicking, orthoretification). The Landsat images were then segmented into homogeneous objects, with represent areas on the ground with similar spatial and spectral characteristics. These objects are related to the distinct land cover types that occur in each municipality. The image segmentation was carried out using the commercial package ENVI-EX, with the following parameters: scale level: 50.0; merge level: 95.0.

The segmentation procedure resulted in 8482 distinct objects (polygons) over the two time periods and four municipalities. The land cover for each object was visually identified, based on its shape, texture and spectral characteristics. Land cover types considered were: sugarcane plantations, pasture lands, natural cover, forest plantation, permanent crop, short cycle crop, water bodies and urban areas.

Results and discussion

An increase in sugarcane planted area in São Paulo state can be seen from 1990 to 2010 (Figure 1), from approximately 2 million hectares in 1990 to over 5 million hectares in 2010, an increase of aproximatelly 145 thousand hectares / year.

INSERT FIGURE 1

Figure 1. Sugarcane planted area from 1990 to 2010 for São Paulo state (top) and the annual percent change index (bottom)

However, this has not been a steady increase over time, with annual variations in the percent of sugarcane expansion. Two main expansion periods can be identified in Figure 1; the first in the 1990s decade, when planted area increased from 1.898.689 ha in 1993 to 2.176.569 ha in 1994 and 2.500.000 ha in 1996. A second strong growth period is seen in 2005 – 2006 years. A reduction in the sugarcane expansion rate is seen from 2009 to 2010.

The percent change index identified 164 sugarcane hotspots in São Paulo State, four of which were selected for detailed land cover mapping: Castilho, Colombia, Narandiba and Palestina (Fig. 2). These four municipalities correspond to approximately 284 thousand hectares.

INSERT FIGURE 2

Figure 2. São Paulo state with the municipalities identified as sugarcane expansion hotspots and the four municipalities where detailed land cover maps were generated

The four municipalities analyzed have shown a strong growth in sugarcane areas (Table 1), as much as 410% increase in Narandiba.

Table 1: Sugarcane planted area (ha) for each municipality in the years 1990 and 2005, identified through remote sensing analysis

INSERT TABLE 1

The cross tabulation between the two land cover maps allows us to evaluate changes through time. However, since we analyze only the beginning and end of a 15 year time period, transitions that undergo more than one land cover change cannot be correctly identified.

Of the area converted to sugarcane plantations by 2005, most of it came from prior pasture lands (Castilho: 60%; Colombia: 67% and Palestina: 69%). These results are similar to the ones obtained by Rudorff et al. (2010), which showed that 56% of sugarcane expansion in São Paulo state, in 2008, occurred over pasture areas. For Narandiba municipality, most of the sugarcane expanded over forest plantations (47%), followed by 29% of pastures being converted to sugarcane (Figure 3). Thus, the land cover transitions observed from 1990 to 2005 are influenced by the land availability and the economical setting of the region. For instance, sugarcane expands most over pasture areas since this is the dominant land cover available over the four municipalities, 143.4 thousand hectares in 1990, close to 50% of the area. However, pasture lands are not the main land cover type in Narandiba, so conversion had to occur over forest plantations.

For two of the municipalities, more than 20% of the 2005 sugarcane plantations expanded over natural cover (Castilho: 27% and Palestina: 21%) while for the other areas, less than 10% of sugarcane expanded over native forests (Colombia: 8% and Narandiba: 3%).

INSERT FIGURE 3

Figure 3. Prior land cover in the year 1990 for the sugarcane plantation areas in 2005 for the municipalities Castilho, Colombia, Narandiba and Palestina, in São Paulo state

Considering the four municipalities, sugarcane area increased from approximately 13 thousand to 66 thousand hectares, taking over 40 thousand hectares of pasture and 11 thousand hectares of natural cover. Meanwhile, some sugarcane areas in 1990 were converted to other land covers in 2005. For instance, close to 2 thousand hectares were converted to pasture in Palestina and 2.6 thousand hectares in Colombia were converted to short cycle agriculture. This last municipality has shown a large increase in short cycle agriculture, from 2.2 thousand ha in 1990 to 13.4 thousand in 2005. Colombia is situated on the NE portion of São Paulo state, an area with high concentration of irrigated, short cycle agriculture, illustrating that the economical setting of the region also influences the land cover dynamics.

Conclusions

The percent change index allowed us to identify the municipalities with strong sugarcane expansion in São Paulo state. This analysis, based entirely on official census data, can be used as a prior selection of the areas where more detailed land cover mapping studies, based on remote sensing, should be carried out. This enable us to better focus the study area, reducing costs and saving resources.

The detailed land cover maps and its change through time showed that the majority of the sugarcane expansion in 2005 occurred over pasture lands. For only one of the municipalities a significant portion of forest plantation was converted to sugarcane. This occurred in a municipality where the forest plantation area was greater than pasture lands.

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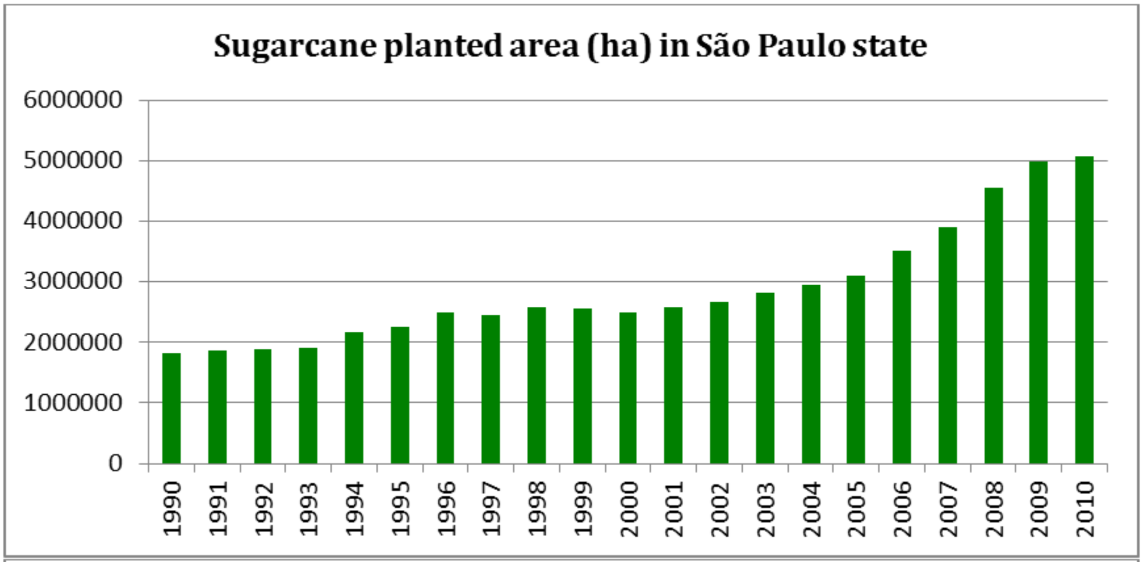
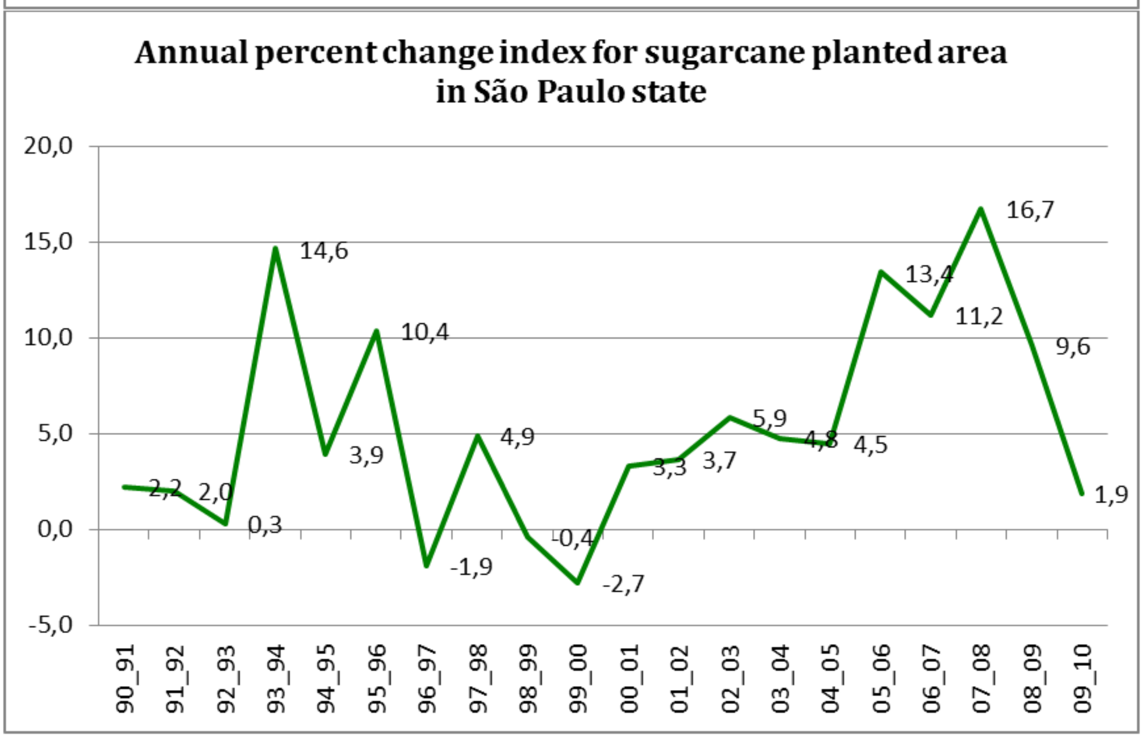
Table

Table 1: Sugarcane planted area (ha) for each municipality in the years 1990 and 2005, identified through remote sensing analysis

Municipality	1990	2005	Increase (%)
Castilho	0	20,387	--
Colombia	7,099	18,474	160
Narandiba	1,640	8,368	410
Palestina	4,207	18,792	347

Figures





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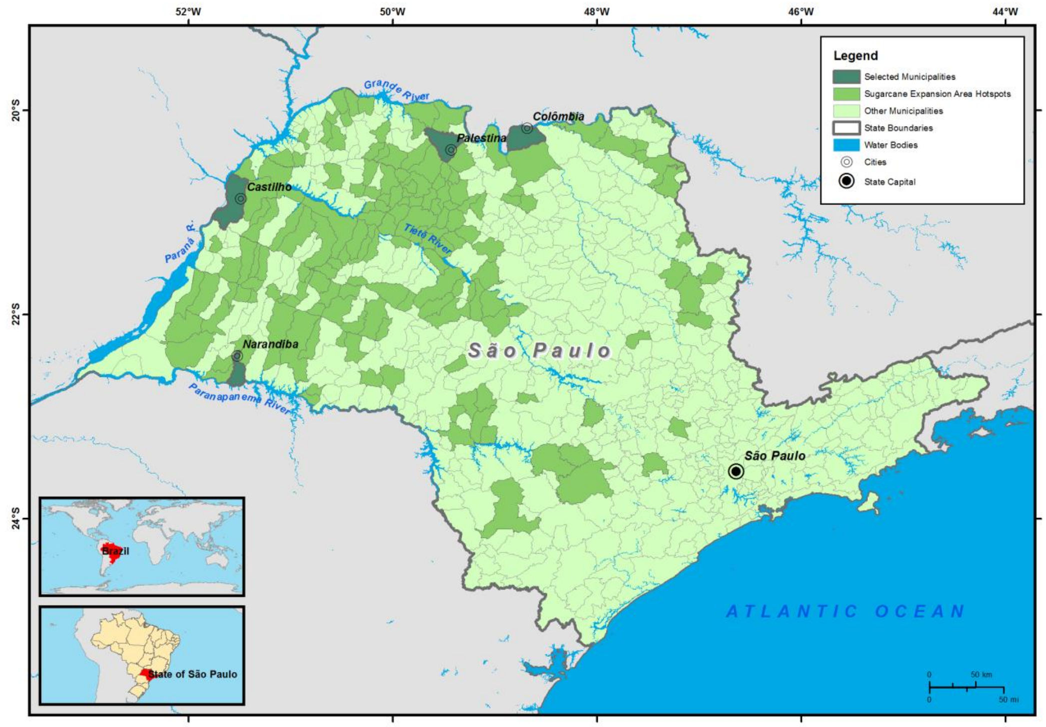

Figure 2. São Paulo state with the municipalities identified as sugarcane expansion hotspots and the four municipalities where detailed land cover maps were generated

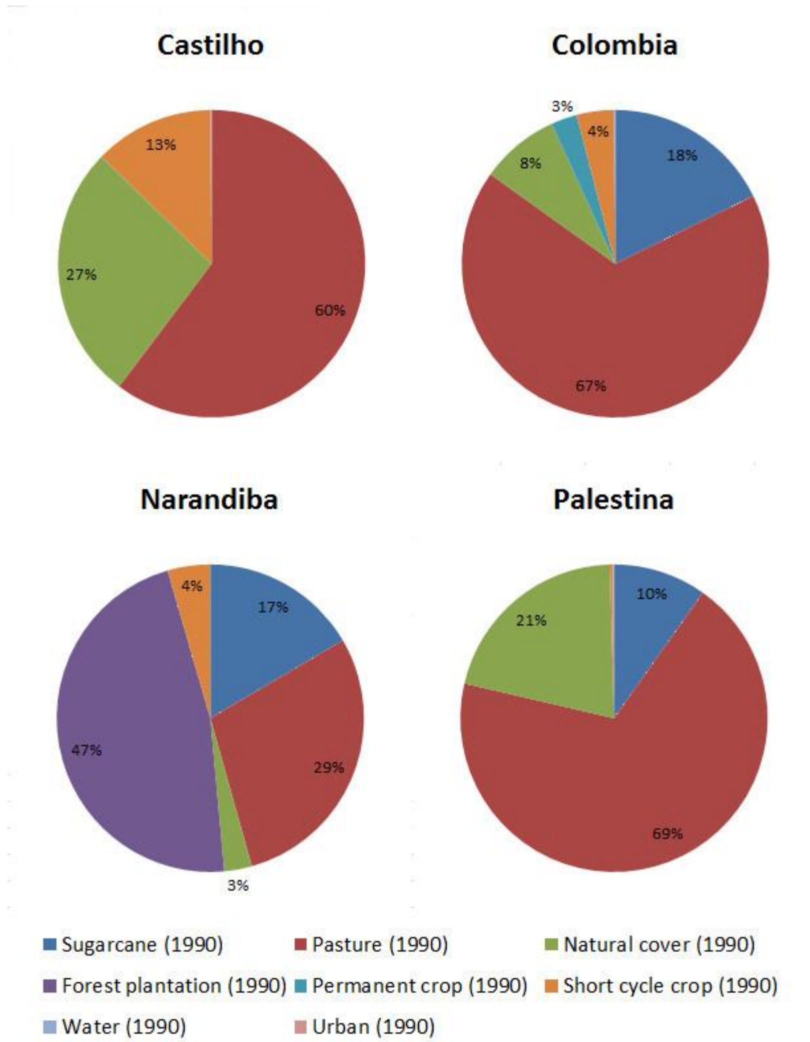

Figure 3. Prior land cover in the year 1990 for the sugarcane plantation areas in 2005 for the municipalities Castilho, Colombia, Narandiba and Palestina, in São Paulo state