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QUANTIFYING THE RAPID SUGARCANE EXPANSION FOR ETHANOL PRODUCTION IN THE RIO GRANDE BASIN, BRAZIL

Kvantifiering av hastig spridning av sockerrörsplantage på grund av etanolproduktion i Rio Grandes avrinningsområde, Brasilien

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Abstract

The search for sustainable sources of energy has found a realistic replacement to fossil fuels in ethanol and methanol. In response to this trend, sugarcane plantations have rapidly increased in Brazil. In this study, this sugarcane expansion was mapped for the River Grande basin in the northern São Paulo, considering the real extension of the plantation area in 1993, 2000, 2007 using Landsat satellite images. Comparisons between these three different land use scenarios showed a significant expansion of sugarcane plantations from 1993 to 2000 and a slight increase from 2000 to 2007.

Key words – Sugarcane expansion, Automatic land use classification, Rio Grande basin, Landsat images

Sammanfattning

Sökandet efter en hållbar energikälla har gett en realistisk ersättare för fossila bränslen i form av etanol och metanol. På grund av denna nya trend har sockerrörsplantagen i Brasilien ökat kraftigt. I denna studie kartlades expansionen av sockerrörsplantagen för River Grandes avrinningsområde i norra delen av São Paulo, med tanke på den verkliga utbredningen av dessa plantager år 1993, 2000 och 2007 med hjälp av satelitbilder från Landsat. Jämförelse mellan dessa tre olika perioder visade en signifikant expansion av sockerrörsplantage från 1993 till 2000 och en liten ökning mellan 2000 till 2007.

Introduction

The high demand for ethanol has made sugarcane the world largest crop, covering an area of 20 million of hectares over more than 70 countries (FAO, 2012; Galdos, 2009). In the beginning of the century, Sweden, for instance, adopted a national strategy to become an oil-independent country by 2020 (Persson, 2006). Most of the ethanol imported to Sweden comes from Brazil (Energimyndigheten, 2012).

Brazil is the country that retains the largest area of sugarcane cultivation in the world. It is responsible for approximately one third of the global harvested area and production (Zuurbier and van de Vooren, 2008). Since 1975, when the Pro-Álcool (ethanol program) started in Brazil as a response to the 1973 oil crisis (e.g. Borges, 1985; Nitsch, 1991), up to 2005, the Brazilian area of sugarcane plantation increased 170 % and reached 5.4 million hectares (Bolling and Suarez, 2001; IEA, 2006). Projections from IEA (2006) estimate the plantation area to reach 12.2 million hectares by 2015. Most of the expansion in sugarcane area during the last 20 years has occurred within São Paulo state and the northern parts of this state are the region where the replacement of the original vegetation called Cerrado, a tropical savannah grassland, by sugarcane plantation has been the most intense (Conab, 2012).

Prior to estimate the impacts of the sugarcane expansion on the water balance, this study aims at mapping land use changes due to sugarcane expansion occurred in the River Grande basin, Brazil, considering the real extension of the plantation area in 1993, 2000, 2007 using Landsat data.

Study area: River Grande basin

The River Grande basin is located in the eastern upper Paraná basin (Figure 1). The basin is also formed by important subsidiaries rivers such as rivers Pardo and Mogi-Guaçu. Approximately 60 % of hydroelectric power generation in Brazil is provided by Paraná River basin of which ~ 12 % comes from the 15 hydropower plants in the River Grande basin (ANEEL, 2005). Its current vegetation cover is formed mainly by remaining Cerrado and agriculture in the low basin and grassland in the high basin. The altitude in the basin varies from 300 to 2700 m.a.s.l. and the soil is composed mostly by agriculture and pasture in the low lands and forest in the high lands.

The original vegetation of the basin has a perennial characteristic, unlike the sugar cane that has a marked annual cycle. Typically, the sugarcane start growing around June (spring in the southern hemisphere) and is harvested about one year later, most commonly after biomass burning. During the sugar cane's one year cycle, the albedo of the field varies from 0.12 to 0.25, and the leaf area index varies from 0.2 to 6 m^2/m^2. The height of the plants reaches up to 3 m.

Data

The U.S. Geological Survey (USGS) provides free access to satellite images around the world. These satellite images have 170 x 183 kilometres with a spatial resolution of 30 m. In this work, they have been used to classify land use as agriculture, forest, sugarcane and pasture.

Methods

Mapping of Sugarcane Plantations

Multi-temporal Landsat images were used for the characterization of sugarcane evolution in the Rio Grande basin. Land use maps were derived through analysis of satellite images made by Landsat TM 7 and extracted from U.S. Geological Survey. The selection of satellite images was driven by the availability of cloud-free Landsat data over the Rio Grande basin from 1970 to 2010. In this study, fourteen Landsat satellite images (170x183 km) were captured in 1993, 2000 and 2007, and used to generate three land use maps.

An automatic classification of Landsat satellite images showed in Rudorff et al. (2010) was used for mapping sugarcane fields. This automatic classification is based on a linear spectral mixing which consists of a linear combination of spectral signatures from two or more types of land use, such as agriculture, pasture, forest etc. Hence, sugarcane fields present a particular spectral signature as described by Rudorff et al. (2010). The sugarcane spectral signature has been used to identify sugarcane fields in the Rio Grande basin. Moreover, a visual inspection was made to support this automatic land use classification.

Each land use map was classified into five dominant types as areas covered by water bodies, Atlantic Forest, agriculture of grain crops, pasture lands and sugarcane fields according to their spectral signatures. Except for sugarcane fields, all spectral signatures were adopted as defined by Mendes and Cirilo (2001).

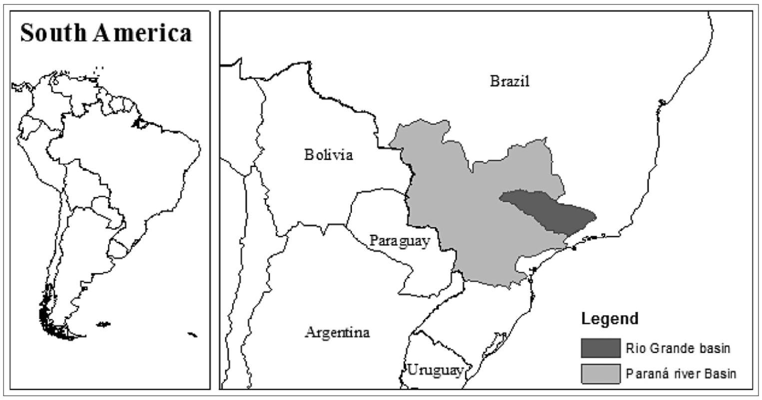

Fig. 1. *Location of Paraná river basin and River Grande basin.*

Results and conclusions

Results from the automatic land use classification in 1993, 2000 and 2007 are presented in figure 2. In order to represent spatial heterogeneity of the sugarcane expansion, the Rio Grande basin was divided into 10 sub-basins as shown in Figure 3.

In general, terrain slope and altitude were equally important factors for sugarcane expansion in the Rio Grande basin once sub-basins with areas which presented terrain slopes lower than 12 % and altitudes varying between 300 and 700 m.a.s.l. significantly increased the concentration of sugarcane fields in their drainage areas. Table 1 shows the percentage of areas covered by sugarcane fields for each sub-basin.

According to table 1, Funil, Camargos and Furnas did not present sugarcane expansion in their drainage areas. This is because, despite having areas with terrain slope less than 12 %, Funil, Camargos and Furnas sub-basins are higher than 800 m.a.s.l.. These results agree with

Table 1. *The portion of areas covered by sugarcane fields per sub-basin in 1993, 2000 and 2007.*

Sub-basin	1993 (%)	2000 (%)	2007 (%)
Funil	0.0	0.0	0.0
Camargos	0.0	0.0	0.0
Furnas	1.5	1.5	1.5
P Colômbia	11.0	20.8	25.9
Marimbondo	27.9	31.1	42.0
A Vermelha	9.4	12.3	30.1

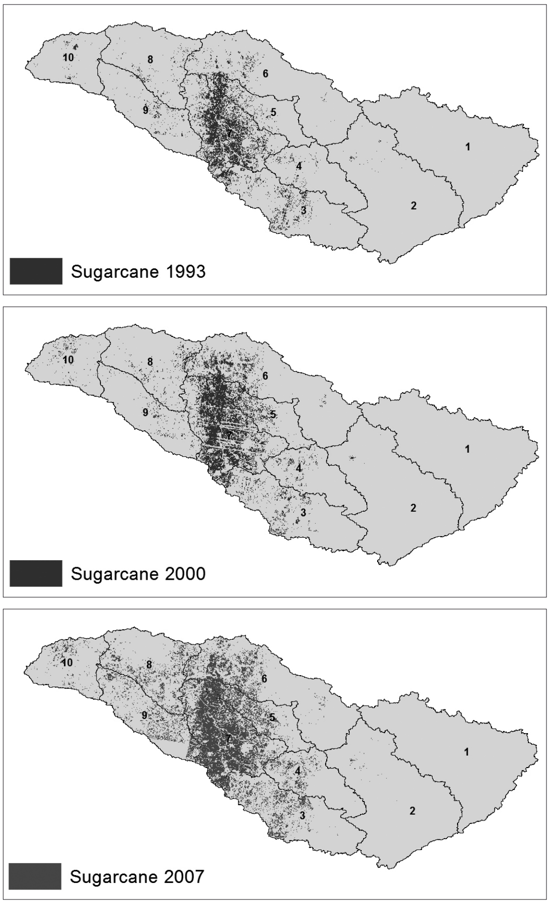

Fig. 2. *Evolution of sugarcane crops for 1993, 2000 and 2007 in the River Grande basin.*

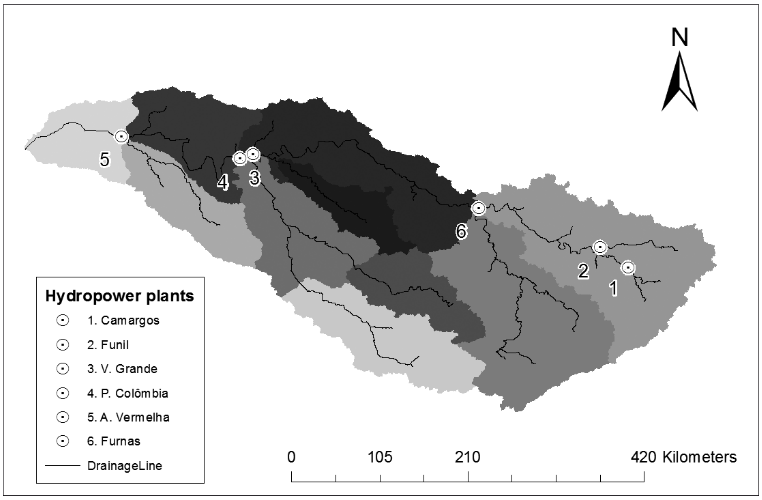

Fig. 3. *River Grande basin divided into 10 catchments and hydropower plants.*

what has been suggested by BRASIL (2009) as areas potentially suitable for cultivation of sugarcane in Brazil.

On the other hand, a significant increase of sugarcane fields is pointed for P Colômbia, Marimbondo and A Vermelha sub-basins. One of the reasons for this rapid sugarcane expansion may be explained by effects of the Pró-Alcool (Brazilian ethanol program) when the Brazilian government provided support to the production of sugarcane (Nitsch, 1991).

A chronological analysis pointed to different expansion rates among P Colômbia, Marimbondo and A Vermelha sub-basins. Between 1993 and 2000, areas covered by sugarcane increased by almost 90 % in P Colômbia whereas, for the same period, Marimbondo and A Vermelha had a sugarcane expansion of only 11.4 % and 30.8 %. In contrast, from 2000 to 2007, sugarcane expansion rates were higher in Marimbondo (35 %) and A Vermelha (140 %) than P Colômbia (22 %). In 2007, sugarcane fields represented approximately 26 % of the P Colômbia sub-basin, 30 % of the A Vermelha sub-basin and more than 40 % of the Marimbondo sub-basin.

Overall, sugarcane fields replaced mostly pasture lands and agriculture of grain crops. Comparisons made between land use distribution in 2007 and 1993 showed that the replacement of pasture lands by sugarcane fields achieved 6.8 %, 7.5 % and 8.9 % of the Marimbondo, P Colômbia and A Vermelha sub-basins. It is followed by agriculture of grain crops with 5.2 %, 4.7 % and 7.6 %, and then Atlantic Forest with 2.1 %, 1.6 % and 3.8 %, respectively.

Regarding the water balance, the influence of sugarcane expansion depended upon a combination of factors, such as amount of areas replaced with sugarcane, type of land use replaced and location of the expansion within each basin. This study showed that the sugarcane expansion mostly impacts the water balance if it happens over the headwater areas with low soil water retention. For these areas, sugarcane expansion significantly increased evapotranspiration rates and reduced soil moisture content and surface runoff.

Researches ongoing are evaluating short-, medium- and long-term impacts of sugarcane expansion on the water balance of the Rio Grande basin, Brazil, as estimated by changes in evapotranspiration, soil moisture content and surface runoff on daily, monthly and annual basis.

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