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Analysis of socioeconomic and environmental sensitivity of sugarcane cultivation using a Geographic Information System

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ABSTRACT

The global interest in biofuels has increased significantly in recent years, mainly due to the concern about climate change. In Brazil, the land area under sugarcane cultivation has expanded in unprecedented ways to meet the increasing ethanol demand of both the domestic and international markets. São Paulo is the Brazilian state with the highest production of sugarcane, and the expansion of this activity can impact both the environment and society. The purpose of this paper was to assess and map the sensitivity of the areas used for sugarcane cultivation in São Paulo state and to provide a holistic approach to sugarcane production from the sustainability perspective by integrating indicators of the environmental, social and economic spheres without focusing on one single element. Five environmental indicators (related to water resources, slope, environmental conservation areas, land use and agricultural potential) and six socioeconomic indicators (related to employment, income, education, gender equality, child labor and forced labor) were selected for the analysis. The methodology comprised the Categorical Principal Components Analysis (CATPCA) technique and the spatialization of results in a Geographic Information System. The resulting maps of sensitivity show the patterns of the three retained principal components and provide an information-rich tool that the government can use in decision making, policy formulation and the integrated planning of land use, thereby enabling the identification of both hotspots and which issues should be prioritized.

1. Introduction

In recent years, the global interest in biofuels has increased significantly, mainly due to the desire to reduce greenhouse gases emissions and mitigate the impacts of climate change. In Brazil, the area with sugarcane expanded in unprecedented ways (Goldemberg et al., 2008; Sparovek et al., 2009; Walter et al., 2011; Adami et al., 2012) to meet the increasing ethanol demand of both the domestic and international markets (Walter et al., 2011).

As the most important state from an economic perspective (responsible for 33% of the country's GDP), São Paulo was selected as the case study. Agribusiness is a very significant activity for a state that has a high level of industrialization, and its contribution to the state's Gross Domestic Product (GDP) is approximately 15% (Cepea, 2014). Within the agriculture of São Paulo, the most significant crop is sugarcane, which is cultivated on approximately 23% of the state's area (IEA, 2014; IBGE, 2015).

The increase in sugarcane production (for sugar and ethanol) from 22.8 million to 40.1 million tons between 2003 and 2014 (IBGE, 2015) in São Paulo state placed it as the largest producer state in Brazil. The fact that sugarcane expansion can impact both the environment and society (Goldemberg et al., 2008; Walter et al., 2011) reaffirms the importance of analyzing indicators from a sustainability perspective, which enables an integrated view of the environmental, social and economic spheres and provides a basis for decision making and for the government to act in the integrated planning of land use.

Agricultural production for non-food purposes has attracted many studies in the environmental and social sciences, which indicates the global concern for sustainable production. As in Abson et al. (2012), this research treated sustainability in an integrated way (using environmental, social and economic aspects) but used the perspective of sensitivity, that is the environment's response to the changes that

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occurred in one or more external factors (e.g., sugarcane production) (Basso et al., 2000). Some studies use indicators to assess impacts on the environment and/or society (Goldemberg et al., 2008; Sparovek et al., 2009; Van der Hilst et al., 2013; Machado et al., 2015; Moraes et al., 2015), and others use geographical information for assessing the suitability of land use using indicators (Abson et al., 2012; Van der Hilst et al., 2013).

Goldemberg et al. (2008), Sparovek et al. (2009), Machado et al. (2015) and Moraes et al. (2015) served as guidance for the choice of indicators, as to what aspects of sustainability were most important. The authors discussed several sustainability aspects of ethanol and sugarcane production in Brazil, mainly in the state of São Paulo. Air quality, air emissions, water availability, water pollution, land use (expansion of sugarcane and competition with food crops), soil, biodiversity, impacts in job and income, working conditions and local quality of life. Goldemberg et al. (2008) bring a review of different impacts on air, water, land use soil, biodiversity, job and income and show what had been done until 2008 when it comes to sustainability assessments. Sparovek et al. (2009) analyzed the implications of sugarcane expansion in Brazil between 1996 and 2006 on indicators for the environment, land use and economy, and found that generally, in the studied period, sugarcane expansion did not contribute to direct deforestation but led to a reduction of pastures and resulted in a higher economic growth than in neighboring areas. Also in a historical approach, Machado et al. (2015) study sugarcane expansion impacts on quality of life from 1970 until 2010, showing better socioeconomic conditions for the selected indicators than the municipalities without sugarcane or with marginal production. In contrast with Sparovek et al. (2009) and Machado et al. (2015), this study aims at not identifying past impacts, but guide expansion in order to minimize such impacts. Moraes et al. (2015) analyzed the socioeconomic impacts related to the working conditions of the Brazilian sugarcane industry, including the sugarcane cultivation and production of sugar and ethanol, compared to the entire agricultural sector in 2012, and they compared two generations of workers (2000 and 2012). Moraes et al. (2015) brings to the table the use of gender inequality indicators and shows the importance of gender in socioeconomic analysis, besides income and employment generation. These authors have identified the important aspects to tackle, but they did not spatialize their results, and this complicates the interpretation because it does not allow the identification of the spatial patterns of the working conditions. Furthermore, their objective was to analyze only past events, while this paper aims at future avoidance of impacts. Also, studies like Machado et al. (2015), although it encompasses the same area of study and provides a profound discussion of the socioeconomic issues, it does not focus on the environmental components required for an integrated analysis, and its results were not mapped, which precluded the identification of patterns or hotspots.

Besides studies focused on sugarcane in Brazil, methodological inspiration comes from Abson et al. (2012) who evaluated the socio-ecological vulnerability of the region of the Southern Africa Development Community (SADC), and Van der Hilst et al. (2013), who evaluated the impacts of biofuel production and its implications for sustainable development in Mozambique, Argentina and Ukraine. Abson et al. (2012) considered vulnerability to be a highly complex phenomenon, with both biophysical and socio-economic factors affecting exposure and sensitivity (Adger, 2006). The authors sought to use spatial mapping techniques to assess the vulnerability of human well-being. They selected twelve indicators and divided them into socio-economic (infant mortality, malnutrition, irrigation, infrastructure poverty, poverty and travel time), environmental and biophysical indicators (agricultural constraints, soil degradation, human appropriation of net primary production (HANPP), available NPP per capita (POPNPP), aridity and coefficient of variation of precipitation). Abson et al. (2012) verified that PCA presented more accurate results than did normalization, highlighting which aspects of vulnerability are present in each ecoregion as well as the differences in each aspect between the ecoregions. The analysis resulted in four principal components being responsible for 63.5% of the variation in the original variables. While Van der Hilst et al. (2013) used indicators that included both environmental (greenhouse gas emissions and impacts on biodiversity, water and soil) and socioeconomic impacts (legality, food security, economic viability, local prosperity, social well-being, labor conditions and gender), but not all of them were used in the analysis. The adopted methodology comprised the production, standardization and summation of the indicators' maps, resulting in a suitability map in which unsuitable or prohibited areas were excluded from being converted to agricultural land. Abson et al. (2012) used a more robust methodology, a holistic approach, and they mapped their results, but they used available indexes and not indicators, which may have introduced a certain bias into the results. Thereby, it was necessary to adapt the methodology to the situation of sugarcane in Brazil.

Our methodology enables the use of a holistic approach for assessing the inter-relations of the aspects that keeps the relations between the original indicators (i.e., their variations in time and space) in the resulting maps, thus allowing the identification of the hotspots and highlighting patterns within the data over an area (Abson et al., 2012). Therefore, useful information for policymakers can be created, indicating which issues should be resolved with priority, and guiding law enforcement in highly sensitive areas. A holistic approach can be achieved using the Principal Component Analysis (PCA) statistical technique, which determines the variables with more influence and their respective weights, built on the percent variability in the data (Petrişor et al., 2012).

This study aimed to assess and map the sensitivity of the areas used for sugarcane cultivation in São Paulo state, intending to provide a holistic approach of the sugarcane production using Categorical Principal Component Analysis (CATPCA), comprising human and ecosystem dimensions (Prescott-Allen, 2011), that is, the socioeconomic and environmental aspects, respectively, for a sustainability analysis. Sensitivity is the response of an environment, or part of it, to changes in one or more external factors (Basso et al., 2000).

2. Material and methods

2.1. The area of study

Located in the country's southeast region, São Paulo state has an area of 248.2 thousand km^2, of which 75 thousand km^2 were planted with seasonal crops (including sugarcane) and 10.3 thousand km^2 were planted with permanent crops in 2014 (IBGE, 2015). Fig. 1 shows the location of São Paulo state and its 645 municipalities.

São Paulo state has five geomorphological units (Coastal Province, Atlantic Plateau, Peripheric Depression, Basaltic Cuestas and Western Plateau) (Ross and Moroz, 1997), with the predominating soils being red-yellow oxisols and ultisols (IBGE, 2001). The dominant climate is Cwa, which covers the central part of the state and is characterized by a tropical climate, with rain in the summer and a dry winter and an average temperature of the warmest month above 22 °C (Cepagri, 2015).

With a production value of US$ 10 bi, or 60% of São Paulo State's agricultural production (2013 values), the sugarcane production is 8 times higher than the production of oranges, which is the second most valuable crop in the state. Corn (US$ 750.7 mi) and soybeans (US$ 726.8 mi) are other important crops in the state (IBGE, 2015).

In addition to the difference in the value of production, the region of concentration varies. Whereas oranges are cultivated in the central part of the state, soybeans and corn share the South and part of the North. Sugarcane, in contrast, is widely spread throughout the state, with 5.7 million hectares in 2013.