ORIGINAL ARTICLE / *ARTIGO ORIGINAL*

Health risks due to pre-harvesting sugarcane burning in São Paulo State, Brazil

Riscos à saúde devido à queima prévia da palha de cana-de-açúcar no Estado de São Paulo, Brasil

Maria Leticia de Souza Paraiso[I], Nelson Gouveia[II]

ABSTRACT: After 2003, a new period of expansion of the sugarcane culture began in Brazil. Pre-harvesting burning of sugarcane straw is an agricultural practice that, despite the nuisance for the population and pollution generated, still persisted in over 70% of the municipalities of São Paulo State in 2010. In order to study the distribution of this risk factor, an ecological epidemiological study was conducted associating the rates of deaths and hospital admissions for respiratory diseases, for each municipality in the State, with the exposure to the pre-harvesting burning of sugarcane straw. A Bayesian multivariate regression model, controlled for the possible effects of socioeconomic and climate (temperature, humidity, and rainfall) variations, has been used. The effect on health was measured by the standardized mortality and morbidity ratio. The measures of exposure to the pre-harvesting burning used were: percentage of the area of sugarcane harvested with burning, average levels of aerosol, and number of outbreaks of burning. The autocorrelation between data was controlled using a neighborhood matrix. It was observed that the increase in the number of outbreaks of burning was significantly associated with higher rates of hospital admissions for respiratory disease in children under five years old. Pre-harvesting burning of sugarcane effectively imposes risk to population health and therefore it should be eliminated.

Keywords: Risk factors. Environmental impact / analysis. Geographical information systems. Respiratory tract diseases / epidemiology. Air pollution / adverse effects. Indicators of morbidity and mortality.

[I]Graduate program in Preventive Medicine of the School of Medicine of *Universidade de São Paulo* – São Paulo (SP), Brazil.
[II]School of Medicine of *Universidade de São Paulo* – São Paulo (SP), Brazil.
Corresponding author: Maria Leticia de Souza Paraiso. Programa de Pós-Graduação em Medicina Preventiva da Faculdade de Medicina da Universidade de São Paulo. Avenida Doutor Arnaldo, 455, 2º andar, CEP: 01246-903, São Paulo, SP, Brasil. E-mail: mlsparaiso@gmail.com.
Conflict of interests: nothing to declare – **Financial support:** none.

RESUMO: Após 2003, teve início um novo período de expansão da cultura da cana-de-açúcar no Brasil. A queima prévia da palha de cana é uma prática agrícola, que, apesar dos incômodos à população e da poluição gerada, ainda persistia em mais de 70% dos municípios do Estado de São Paulo, em 2010. A fim de estudar a distribuição desse fator de risco, realizou-se um estudo epidemiológico ecológico associando as taxas de óbitos e as internações por doenças respiratórias, para cada município do Estado, com a exposição à queima prévia da palha de cana. Foi aplicado um modelo Bayesiano de regressão multivariada, sendo controlado para os possíveis efeitos das variações socioeconômicas e climáticas (temperatura, umidade e precipitação). O efeito sobre a saúde foi medido por meio da razão de mortalidade e morbidade padronizada. Como medidas de exposição à queima prévia foram usadas o percentual da área de cana colhida com queima, os níveis médios de aerossol e a quantidade de focos de queima. A autocorrelação entre os dados foi controlada pelo emprego de uma matriz de vizinhança. Observou-se que o aumento no número de focos de queima esteve associado significativamente com o aumento das internações por doenças respiratórias na faixa etária de menores de cinco anos. A queima prévia da palha da cana-de-açúcar oferece efetivamente risco à saúde da população, portanto sua eliminação deve ser promovida.

Palavras-chave: Fatores de risco. Impacto ambiental/análise. Sistemas de informação geográfica. Doenças respiratórias/epidemiologia. Poluição do ar/efeitos adversos. Indicadores de morbidade e mortalidade.

INTRODUCTION

Since 2003, with the introduction of flex-fuel vehicles (running on ethanol or gasoline) in Brazil, a new period of expansion of the sugarcane culture began. This was combined with the international environment issues that promote the application of biofuels, due to the need for the use of ethanol to replace fossil fuels to reduce emissions of greenhouse gases (GHG)[1]. The State of São Paulo is the largest producer of sugarcane in Brazil and accounted for, in 2010, 54 and 20% of national and global production of ethanol, respectively, according to estimates from the Brazilian Supply Company (Conab)[2,3]. Thus, between 2006 and 2010, there was an increase of more than 1.5 million hectares of sugarcane, and it was found that 74% of municipalities in the State had the practice of pre-harvesting burning of sugarcane straw[4]. Until the early 1950s, the cane fields were harvested by hand and without pre-harvesting burning. Only after the introduction of mechanical shovels, this has been introduced to increase the productivity of manual cutting. Straw, then, is no longer used to make cane sheaves and was from then on burned before harvesting[5]. With this innovation and the adoption payment per production to the cutters, labor productivity grew 2.5 to around 12 tons of sugarcane cut per day.

Pre-harvesting straw burning of sugarcane generates a huge amount of air pollutants such as aerosols, fine ($PM_{2,5}$) and coarse (PM_{10}) particulate matter, gases such as carbon monoxide (CO) and carbon dioxide (CO_2), aldehydes (acrolein, formaldehyde), methane (CH_4), nitrogen oxides (NOx), nitrous oxide (N_2O), other hydrocarbons and polycyclic aromatic hydrocarbons (PAHs)[6]. Once in the atmosphere, some of these gases - such as methane,

NO$_2$ and hydrocarbons — may produce secondary pollutants such as ozone (O$_3$), through photochemical reaction[7].

Most toxic environmental pollutants enter the human body through inhaled air. Considering that an adult at rest has pulmonary ventilation of approximately 8,640 L per day, air pollution has an important cumulative effect, and one should take into account the exposure time, the breathing pattern and the solubility of the chemical involved. The nose "filters" air impurities, but its ability to remove particulate material depends on the size and other physical properties of the particles. Thus, particles larger than 10 μm are effectively retained in the nose, while those smaller than 2,5 μm reach the deepest parts of the respiratory system[8]. They transpose the epithelial barrier, reach the lung tissue and are responsible for triggering the inflammatory process. Chronic inflammation of the bronchial tree and parenchymal destruction can lead to cases of chronic obstructive pulmonary disease (COPD). The accumulation of mucus in the bronchial tree predisposes to episodes of respiratory tract infection.

The association between pre-harvesting sugarcane burning and its effects on health has been demonstrated by several authors[7-14] and by different methods, but such agricultural practice still persists. For about 60 years, this pollution has been impacting the health of the State's population. This study focused on the population of hundreds of Sao Paulo sugarcane municipalities, which during most of the year suffer from their effects. In these, fires have become so present that they are considered just another component of the landscape of such cities.

Thanks to popular pressure, in 2002, Law 11.241 was approved in the State, which provides for the elimination of sugarcane straw burning and sets a timetable from 2002 to 2031, with the percentage of planted areas where burning should be eliminated, from 20% in the first year to 100% in 2021, for mechanized areas, and by 2031 for non-mechanized[4,12]. In 2007, mill owners, represented by the Union of the Sugarcane Industry (Única), and sugarcane suppliers, represented by Orplana, signed a voluntary agreement for the elimination of pre-harvesting burning of sugarcane straw, the *"Protocolo Ambiental"* (Green Agricultural Protocol). The Department of the Environment of the State of São Paulo reported that, in 2010, more than 94% of the sugarcane produced already obeyed the directives established by the Protocol. However, it is known that the burning of sugarcane straw and the consequent emission of pollutants will also impact the health of sugarcane areas of the State until at least 2017, as there may still be a delay in its implementation[4].

In order to bring a new contribution, an ecological study has been proposed, as well as in the Lopes and Uriarte investigations[10,13], using the municipality as the unit of analysis and controlled for confounding, climatic and socioeconomic factors. The objective of this study was to demonstrate that there is an association between the pre-harvesting burning and the risk to health, regardless of these factors, and to show its distribution in the municipalities of São Paulo. Thus, it seeks to make a contribution to the elimination of pre-harvesting burning and/or adoption of preventive measures in relation to health problems, while this agricultural practice persists.

METHODS

An ecological epidemiological study was conducted, relating indicators of exposure to burning of sugarcane straw and health effects, with the 645 municipalities in the State of São Paulo as the unit of analysis, in 2010. The population of the São Paulo municipalities where, in 2010, pre-harvest burning of sugarcane occurred, was considered as the population exposed to burning of sugarcane straw. The health effects were measured by standardized mortality and morbidity ratio (SMR), built from the variables deaths from respiratory diseases (Chapter X of the 10th Revision of the International Classification of Diseases - ICD-10), in the age groups above 65 year old; and hospital admissions for respiratory disease in age groups of under five and over 65 years in each municipality. Both variables were taken from the IT Department of SUS (DATASUS)[10], of the Ministry of Health. We chose to use comprehensive data on respiratory diseases due to concern about the reliability of diagnoses from secondary databases.

The reference rate used for indirect standardization was the total number of hospitalizations and deaths in the State. However, such values of the standard ratios are not independent estimates, i.e., possess spatial dependency (municipality with the other neighbors), also known as autocorrelation[15]. To deal with the aforementioned instability in the SMR estimates and its autocorrelation, a first order neighborhood matrix was used, and a full hierarchical Bayesian model was adopted[16].

To further reduce the noise in the analysis, months that had no record of outbreaks were removed, since there is no exposure to pre-harvesting burning of sugarcane in them. To this end, we analyzed the monthly number of burning outbreaks obtained through satellite images from the Brazilian Institute for Space Research (INPE), obtained at http://sigma.cptec.inpe.br/queimadas/. From 2006 to 2010, outbreaks ranged from 55 to 2,255 and concentrated from April to October, according to Table 1, so this was the period chosen for the study. In addition, we chose to use indirect measures of exposure to the burning of sugarcane straw. With the ease of access to INPE data, three measures were tested: Sum of Monthly Total Points of Burning Outbreaks (Outbreaks); Sum of Monthly Average Optical Depth of Aerosols (Aerosols) and Percentage (%) of Burning per Municipality (PBM), area of sugarcane harvested with burning, obtained from CANASAT Project (available at: http://www.dsr.inpe.br/laf/Canasat/index.html). This was divided by the official area of the municipality. This was done for each of the 645 municipalities whose boundaries are defined by the Brazilian Institute of Geography and Statistics (IBGE), according to information at http://www.ibge.gov.br/home/default.

Based on weather data from the Environmental Information Integrated to Environmental Health System (SISAM), a partnership between the Ministry of Health and INPE, the INPE-SISAM Portal (available at: http://sisam.cptec.inpe.br/sisam), which provides daily and monthly data obtained by remote sensing or modeling, for all Brazilian municipalities, and, from the correlation analysis between these climatic variables and outcomes, the variables selected were: minimum humidity (%) and maximum temperature (°C), which, along with

the monthly average of accumulated precipitation (mm/m²), were included in the model. The socioeconomic variables on educational conditions, sanitation and income, taken from the publication "Municipal Social Indicators"[17], based on the Brazilian 2010 Census, completed the regression equation.

The proposed model considered that the number of cases of deaths or hospitalizations for respiratory diseases observed by municipality (Di) follows an exponential function with the Poisson distribution. The mathematical and computational advantages that the logarithmic transformation provides allowed the testing of the model described by Equation 1:

$$Ln\ (Di)\ /\ (Ei) = \alpha_i + \beta_1\ Exp.\ factor + \beta_2\ precipitation$$
$$+\beta_3\ maximum\ temperature + \beta_4\ minimum\ humidity$$
$$+\beta_5\ (\%)\ sanitation + \beta_6\ (\%)\ illiteracy + \beta_7\ (\%)\ income\ (1/2\ minimum\ wage)$$
$$I = 1,\ 2,...,\ 645. \tag{1}$$

In which:

Di = number of cases of deaths or hospitalizations for respiratory diseases, observed in individuals aged under five years or over 65 years in municipality i;

E_t = number of events expected in municipality i;

α_i = natural logarithm of the relative risk of municipality i;

α_k = effect of the parameters adjusted in municipality i;

Exp. factor = (PBM, Aerosol, Outbreaks) indirect exposure to burning.

Table 1. Points of burning outbreaks in the State of São Paulo, from April to October, 2006 to 2010.

Points/year month	2006	2007	2008	2009	2010	Total points/ month
January	256	55	77	233	104	725
February	236	185	67	123	443	1054
March	385	494	147	201	518	1745
April	1167	669	270	1230	879	4215
May	2335	994	733	1480	1108	6650
June	3232	1315	500	942	1853	7842
July	3893	993	1801	986	3393	11066
August	5785	2786	1947	1822	5785	18125
September	5236	3564	2775	993	6074	18642
October	2020	2130	1128	972	2255	8505
November	1357	783	1576	796	1449	5961
December	145	467	1430	273	317	2632
Σ 7 months (Apr. to Oct.)	23,668	12,451	9,154	8,425	21,347	

Source: INPE data for all satellites.

The analysis was performed using the MCMC estimation method (Markov Chain - Monte Carlo), through the free software WinBUGS 1.4.0[18] (Win Bayesian inference Using Gibbs Sampling), suitable for Bayesian analysis of complex models. For each outcome and municipality, approximately 10,000 interactions were performed, until the setting that best "softened" SMR estimates was obtained for each modeling. For this, only one Markov chain was used and the $\alpha = 5\%$ significance level was adopted.

This study was approved by the Ethics Committee for Analysis of Research Projects of Hospital das Clínicas, School of Medicine, Universidade de São Paulo (HCFMUSP).

RESULTS

The database was composed of the 645 municipalities in the State of São Paulo. Data provided by CANASAT Project/INPE showed 483 municipalities being monitored to verify the pre-harvesting burning of sugarcane straw in 2010, but as in seven of them, the burned area was practically zeroed, 476 remained for analysis. For the descriptive analysis of the variables in the State municipalities, shown in Table 2, it was observed that the percentage of the area of sugarcane harvested with burning (PBM) of each municipality ranged from 4.7 to 47.6%; the points of burning outbreaks ranged from 6 to 950 and the aerosol, 0.19 to 0.49, with a mean of 0.33. The SMR for the outcome "deaths" of the age group over 65 years ranged from 0.61 to 4.64 with a mean of 0.96; for the outcome "hospitalizations" for the age group over 65 years, the SMR ranged from 0.86 to 8.63 with a mean of 1.58 and, in children aged under five years, from 1.52 to 7.61 with an average of 1.18. It is noteworthy that the SMRs showed instability to express the risk, since these outcomes are relatively rare and often calculated on a small population, which could indicate just a casual occurrence of one or two cases - more or less - in a particular locality. Consequently, if the analysis was to be produced with these raw data, it would not properly represent the process under study[15].

Thus, with the Bayesian analysis, a standardized mortality or morbidity ratio were recalculated and adjusted for each municipality in the State. Each measure or exposure factor was analyzed separately and the results are shown in Table 3. Statistically significant association (p = 0.008) was observed between the increase in the number of points of burning outbreaks and the hospitalizations for respiratory diseases for children under five years old. Other outcomes and the exposure measurements analyzed were not significant.

DISCUSSION

This study, as well as others in the State of São Paulo[8-11,13,14], showed that there is an association between the pre-harvesting burning of sugarcane straw and the occurrence of respiratory diseases, especially in children under five years old. The geospatial analysis

Table 2. Descriptive analysis of the variables in the model for respiratory diseases and pre-harvesting burning of sugarcane straw, in São Paulo State municipalities, from April to October, 2010.

Variable	Mean	SD	Minimum	P25	Median	P75	Maximum
SMR (Deaths > 65 years old)	0.96	0.58	0	0.60	0.93	1.24	4.64
SMR (Hospitalization < 5 years old)	1.18	0.96	0	0.56	0.92	1.52	7.60
SMR (Hospitalizations > 65 years old)	1.58	1.07	0	0.85	1.39	2.08	8.63
Burning outbreaks	33.71	70.20	0	0	6	38	950
Precipitation	51.32	8.08	31.47	45.36	51.41	56.76	82.10
Aerosol	2.91	0.50	1.5	2.6	2.9	3.2	5.20
PBM	7.80	9.15	0	0	4.69	11.57	47.59
Maximum temperature	23.70	2.05	18.06	22.35	23.9	25.47	27.19
Average temperature	19.86	1.75	15.39	18.5	20.06	21.31	22.79
Minimum temperature	16.37	1.23	13.35	15.37	16.3	17.37	18.86
Maximum humidity	88.06	3.21	81.4	85.24	88.95	90.50	94.45
Average humidity	73.60	5.45	65.61	68.42	73.52	78.91	84.51
Minimum humidity	57.49	6.38	48.82	51.31	56.74	62.42	71.35
Precipitation	51.32	8.08	31.47	45.36	51.41	56.76	82.10
% sanitation	80.28	15.42	20.86	73.83	84.43	91.27	99.93
% illiteracy	7.62	2.68	1.45	5.58	7.49	9.35	17.10
% income up to 1/2 minimum wage	24.70	9.58	5.64	18.13	23.22	29.10	65.74

SMR: standardized morbidity and mortality ratio; PBM: percentage of the area of sugarcane harvested with burning per municipality; SD: standard deviation; Humidity (%), Temperature (°C), Precipitation (mm/m^2).
Sources: SIM/SVS/MS, SIH/SUS/MS, SISAM/INPE IBGE.

Table 3. Standardized and adjusted mortality and morbidity ratio for pre-harvesting burning, in São Paulo State municipalities, from April to October, 2010.

Outcomes	Mean	SD	P25	Median	P75	p-value
SMR deaths > 65 years						
PBM	0,00353	0,00254	-0,00135	0,00350	0,00857	0,165
Aerosol	0,01491	0,04705	-0,06641	0,01460	0,11260	0,751
Outbreaks	0,00013	0,00019	-0,00023	0,00013	0,00050	0,477
SMR hospitalization < 5 years						
PBM	0,00131	0,00518	-0,00769	0,00113	0,01214	0,800
Aerosol	-0,10380	0,06417	-0,24550	-0,11310	-0,00804	0,106
Outbreaks	0,00080	0,00030	0,00017	0,00081	0,00135	0,008
SMR hospitalization > 65 years						
PBM	0,00708	0,00450	-0,00188	0,00694	0,01624	0,116
Aerosol	0,01487	0,05267	-0,05834	-0,00409	0,10980	0,788
Outbreaks	-0,00004	0,00028	-0,00061	-0,00004	0,00049	0,872

PBM: percentage of the area of sugarcane harvested with burning per municipality; SMR: standardized mortality and morbidity ratio; SD: standard deviation.

of the distribution of the adjusted SMR indicated that, for each increment of a point of burning outbreak, the SMR for hospitalizations for respiratory diseases in children under five years old increases, on average, 0.0008%.

These studies cited, by using different methodologies from the one employed here, make it impossible to directly compare their results, despite the common object of study. However[12,14], their results agree with this study, indicating association between burning of sugarcane straw and respiratory diseases in children.

Ecological studies generally suffer limitations due to the use of aggregate data, because they do not offer the possibility of applying the results directly to the individual level. However, considering that "the causes of disease in individuals differ from the causes of incidence in the population", the difference (excess) in illness rates in the 645 municipalities in the State of São Paulo was examined, in order to verify the effect of "pre-harvesting burning" of sugarcane straw. Therefore, we noticed the health condition of the population of each municipality and not of the individual, so this study can provide effective and applicable results on the definition of public health policies. Thus, although it is not possible to state categorically that the hospitalizations observed had the practice of pre-harvesting burning of sugarcane straw as the cause of illness, it is possible to, through this type of study, get maps showing the excess of risk of respiratory diseases territorially distributed in São Paulo.

Spatial analysis tools used to control the autocorrelation allowed the simultaneous study of the influence of many variables that could play a role in the disease process. Thus, the issue of health was analyzed from a completely ecological perspective, that is, all variables (exposure, disease and covariates) were ecological measures, as they have been extracted from the aggregate under consideration (municipality), taking health and disease in the environmental and socioeconomic contexts. The matrix approach used also allowed us to verify the influence of the municipalities on their neighbors.

Failure to remove cases of respiratory diseases due to smoking/tobacco is another limitation to be considered. However, as the analysis was stratified by age group, and the significant result obtained was for the group of children under five, the problem is reduced to secondhand smoking. Furthermore, it is considered that the same type of question could occur in all municipalities regardless of the presence or absence of pre-harvesting burning of straw. So this may have caused only a non-differential misclassification.

As for the climate data used, access to the SISAM/INPE Portal made it possible to obtain climate data for each individual municipality, which increases the quality of this analysis, which could be even more accurate if they were used, instead of annualized data or monthly climate information[14].

Another change that could improve estimates would be the exchange of exposure measurements. The fact that the burning percentage (PBM) was used instead of the harvesting areas with burning may have hampered the investigation, because a large area of burning may represent proportionally little in case it is located in a municipality with a large

territory. This variable should therefore be replaced by the gross area of harvest with burning in the municipality, or by the value of the emissions of the sugarcane sector, calculated from the new burning emission factor estimated by INPE[19].

The current scientific knowledge shows that air pollution causes many health problems aside from respiratory diseases, such as cardiovascular disease[20] and cancer[22-23]. Nevertheless, in this study, we chose to use only the outcome of respiratory diseases. Therefore, the impact on health due to pre-harvesting burning of sugarcane straw is probably underestimated.

Regarding socioeconomic variables, "education", "sanitation" and "income" were used, as published in the "Municipal Social Indicators" series[17]. This publication was developed based on demographic data of the Brazilian Census 2010, the same year of the information collected, ensuring, therefore, accuracy in the analysis.

As a simplification of reality, a model has always a way of being improved and is never completely correct[24]. In any case, even if the limitations raised are relevant, this does not invalidate the results.

This study may contribute to the adoption of clear public policies towards the elimination of burning as an agricultural practice and to guarantee the right to health and to a sound environment for the entire population, as provided in the Federal Constitution of 1988. It is noteworthy that, despite the adoption by the São Paulo sugarcane industry of the proposition for elimination of pre-harvesting burning of sugarcane straw, serving as an example of social and environmental responsibility to other States in Brazil where pre-harvesting burning of sugarcane straw is practiced, it is not mandatory. However, as this initiative has not yet become law[18], being only an agreement, it is important to monitor its developments and verify the progress or not in this area. This attention is also valid for other sectors of agriculture, where burning is a common practice and the government's efforts to eliminate them have had little success[25].

The Department of Health Surveillance of the Ministry of Health implemented the "Programa Vigiar" ("To watch" program) to measure, assess and prevent health risks to the population exposed to environmental factors related to air pollution. The results show that the pre-harvesting burning of sugarcane straw does offer health risks to the population even in small municipalities[21], where there is no regular measurement of air pollution by the São Paulo State Environmental Company (CETESB). In addition, the findings may also offer resources for action from epidemiological surveillance and for the establishment of air pollution control policies that address these municipalities and major urban centers.

It is also observed that the lawsuits brought in "sugarcane municipalities" to eliminate the burning are rejected as unfounded, due to an alleged lack of evidence to justify its ban[26,27]. The few actions considered well founded were tried under the "precautionary principle"[27,28], which aims to ensure the protection against potential risks that have not been scientifically proven in the current state of knowledge.

CONCLUSIONS

The decision to burn or not the sugarcane straw should be treated not only as an economic, political, social and environmental issue, but also as a health problem. This discussion brings up the current and recurring theme of development linked to the preservation of the environment and quality of life. In addressing the activity of sugarcane burning regarding the health of the population of the State of São Paulo, the distribution of an economic factor, the harvesting of sugarcane with 'straw burning' and its impact on population health were studied. The incidence of diseases is a consequence of the behavior of society and the social and economic impacts of the strength of the markets.

Therefore, the problems generated by the pre-harvesting burning of sugarcane straw on the health of the population of sugarcane municipalities should be recognized. Data of harvesting with burning in the municipalities and the indicators of morbidity and mortality from respiratory diseases analyzed subsidize the defense of the elimination of pre-harvesting burning of sugarcane and its replacement by its cut without burning (GH). In view of the results, the elimination of pre-harvesting burning of sugarcane straw has proven to be a necessary measure to improve the health of the São Paulo State population.

Confronted with evidence that exposure to air pollutants has a measurable impact on human populations, it is necessary to implement epidemiological surveillance of people exposed to burning. The elimination of this risk factor should be part of the primary health prevention measures to be adopted in the State.

REFERENCES

1. Martinelli LA, Filoso S. Expansion of sugarcane ethanol production in Brazil environmental and social challenges. Ecol Appl 2008; 18(4): 885-98.

2. Companhia Nacional de Abastecimento – Conab. Acompanhamento de safra brasileira: cana-de-açúcar, terceiro levantamento, janeiro/2011. Brasília: Conab; 2011.

3. Rudorff BF, Aguiar DA, Silva WF, Sugawara LM, Adami M, Moreira MA. Studies on the rapid expansion of sugarcane for ethanol production in São Paulo State (Brazil) using Landsat data. Remote Sens 2010; 2(4): 1057-76.

4. Aguiar DA, Rudorff BF, Silva WF, Adami M, Mello MP. Remote sensing images in Support of Environmental Protocol: monitoring the sugarcane harvest in São Paulo State, Brazil. Remote Sens 2011; 3(12): 2682-703.

5. Ripoli TC, Ripoli ML. Biomassa de cana-de-açúcar: colheita, energia e ambiente. Piracicaba: Edição dos autores; 2009.

6. Arbex MA, Cançado JE, Pereira LA, Braga AL, Saldiva PH. Queima de biomassas e efeito sobre a saúde. J Bras Pneumol 2004; 30(2): 158-75.

7. Ribeiro H, Assunção JV. Efeitos das queimadas na saúde humana. Rev Estud Avançados 2002; 16(44): 125-48.

8. Arbex MA, Martins LC, de Oliveira RC, Pereira LA, Arbex FF, Cançado JE, et al. Air pollution from biomass burning and asthma hospital admissions in a sugar cane plantation area in Brazil. J Epidemiol Community Health 2007; 61(5): 395-400.

9. Cançado JE. A poluição atmosférica e sua relação com a saúde humana na região canavieira de Piracicaba – SP [tese]. São Paulo: Faculdade de Medicina da Universidade de São Paulo; 2003.

10. DATASUS. Processamento de Dados do SUS. Procedimentos hospitalares do SUS. Disponível em: http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sih/cnv/prsp.def (Acessado em 8 de janeiro de 2012).

11. Lopes FS, Ribeiro H. Mapeamento de internações hospitalares por problemas respiratórios e possíveis associações à exposição humana aos produtos da queima da palha de cana-de-açúcar no Estado de São Paulo. Rev Bras Epidemiol 2006; 9(2): 215-25.

12. Ribeiro H, Pesquero C. Queimadas de cana-de-açúcar: Avaliação de efeitos na qualidade do ar e na saúde respiratória de crianças. Estudos Avançados 2010; 24(68): 255-71.

13. Arbex MA, Martins LC, Oliveira RC, Pereira LA, Arbex FF, Cançado JE. Impact of outdoor biomass air pollution on hypertension hospital. J Epidemiol Comm Health 2010; 64(7): 573-9.

14. Uriarte M, Yackulic CB, Cooper T, Flynn D, Cortes M, Crk T, et al. Expansion of sugarcane production in São Paulo, Brazil: implications for fire occurrence and respiratory health. Agro Ecosyst Environ 2009; 132(1-2): 48-56.

15. Kato SK, Vieira DM, Fachel JM. Utilização da modelagem inteiramente bayesiana na detecção de padrões de variação de risco relativo de mortalidade infantil no Rio Grande do Sul, Brasil. Cad Saúde Pública 2009; 25(7): 1501-10.

16. Bernardinelli L, Montomoli C. Empirical Bayes versus fully Bayesian analysis of geographical variation in disease risk. Stat Med 1992; 11(8): 983-1007.

17. Brasil. Ministério do Planejamento, Orçamento e Gestão. Instituto Brasileiro de Geografia e Estatística. Indicadores Sociais Municipais: uma análise dos resultados do universo do Censo Demográfico 2010. Rio de Janeiro: FIBGE; 2011.

18. Lunn DJ, Thomas A, Best N, Spiegelhalter D. WinBUGS – a Bayesian modelling framework: concepts, structure, and extensibility. Stat Computing. 2000; 10: 325-37.

19. Cançado JE, Braga A, Pereira LA, Arbex MA, Saldiva PH, Santos UP. Repercussões clínicas da exposição à poluição atmosférica. J Bras Pneumol 2006; 32 (Supl. 2): S5-11.

20. Roseiro MN, Takayanagui AM. Morbidade por problemas respiratórios em Ribeirão Preto (SP) de 1995 a 2001, segundo indicadores ambientais, sociais e econômicos. Rev Paul Pediatria 2006; 24(2): 163-70.

21. França DA, Longo KM, Neto TG, Santos JC, Freitas SR, Rudorff BF, et al. Pre-Harvest sugarcane burning: determination of emission factors through laboratory measurements. Atmosphere 2012; 3(1): 164-80.

22. Pope III CA, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, et al. Lung Cancer, Cardiopulmonary Mortality, and long-term exposure to fine particulate air pollution. JAMA 2002; 287(9): 1132-41.

23. Fajersztajn L, Veras M, Barrozo LV, Saldiva P. Air pollution: a potentially modifiable risk factor for lung cancer. Nat Rev Cancer 2013; 13(9): 674-8.

24. Box GE, Leonard T, Wu CF (Eds.) Scientific inference, data analysis, and robustness. New York: Academic Press; 1983.

25. Sá TD, Kato OR, Carvalho CJ, Figueiredo RO. Queimar ou não queimar? De como produzir na Amazônia sem queimar. Rev USP 2007; 72: 90-7.

26. Gonçalves DB. Sob as cinzas dos canaviais: o perigoso impasse das queimadas no Estado de São Paulo. Informações Econ. 2005; 35(8): 32-43.

27. Avólio EG. Da (i)licitude das queimadas da palha da cana-de-açúcar [dissertação]. São Carlos, São Paulo: Escola de Engenharia de São Carlos da Universidade de São Paulo; 2002.

28. Goldim JR. O princípio da precaução. Núcleo Interdisciplinar de Bioética da UFRGS. 2002. Disponível em: http://www.bioetica.ufrgs.br/precau.htm (Acessado em 06 de junho de 2013).