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ESTUDO ECOLÓGICO DOS EFEITOS DO MATERIAL PARTICULADO ATMOSFÉRICO INALÁVEL SOBRE A POPULAÇÃO DO MUNICÍPIO DE PIRACICABA-SP.

Dissertação apresentada à Faculdade de Odontologia de Piracicaba, Universidade Estadual de Campinas, para obtenção do título de Mestre em Odontologia em Saúde Coletiva

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“A raposa calou-se e olhou por muito tempo para o principezinho.

- Cativa-me, por favor, disse ela.

- Tenho muito gosto, respondeu o principezinho, mas falta-me tempo. Preciso fazer amigos e conhecer outras coisas deste mundo.

- Só se conhece bem as coisas que se cativa, disse a raposa. Os Homens já não têm mais tempo para conhecer melhor as coisas. Compram tudo pronto nas lojas. Mas como não existem lojas de amigos, os Homens já não têm mais amigos. Se queres um amigo, cativa-me.

- O que hei de fazer? disse o principezinho.

- Tens de ter muita paciência, respondeu a raposa. Primeiro, senta-te um pouco afastado de mim, assim, na relva. Eu olho para ti pelo canto do olho e tu não dizes nada. A linguagem é uma fonte de mal-entendidos. Mas, dia após dia, podes sentar-te cada vez mais perto...

- Vou dizer-te um segredo. É muito simples: Só se vê bem com o coração. O essencial é invisível aos olhos”.

Antoine de Saint-Exúpery

RESUMO GERAL

Inúmeros estudos apontam para associações entre os eventos de poluição atmosférica e o aumento nas taxas de mortalidade por doenças do aparelho circulatório e respiratório. O município de Piracicaba-SP, é considerado um pólo nacional de produção industrial contando com indústrias do ramo da siderurgia e usinas de álcool e açúcar que demandam uma grande área plantada com cana-de-açúcar, em que, comumente se emprega o fogo previamente à colheita da lavoura, gerando assim, uma excessiva produção de material particulado. O presente estudo buscou verificar a associação entre óbitos por doenças do aparelho circulatório e respiratório, e as concentrações atmosféricas do poluente material particulado inalável *de 10 μm de di*âmetro (PM_{10}). O presente trabalho foi dividido em dois artigos de pesquisa epidemiológica, realizados na cidade de Piracicaba-SP. No primeiro artigo analisou-se a associação estatística entre as variáveis concentração atmosférica de material particulado inalável urbano e óbitos por doenças do aparelho circulatório e respiratório, controlando as variáveis sazonais de confusão: umidade relativa do ar e temperatura. Os resultados apresentaram uma correlação estatisticamente significativa para as variáveis umidade relativa do ar e concentração atmosférica de material particulado, e uma correlação fraca para óbitos por doenças do aparelho circulatório e concentração atmosférica de material particulado - RR: 1,006 (1,002-1,010) - demonstrando que variações interquartis na concentração do poluente em estudo geram aumentos nas taxas de óbitos por doenças do aparelho circulatório e respiratório. Pode-se concluir neste estudo, que o poluente material particulado apresenta correlação inversa com a variável sazonal umidade relativa do ar, e que as taxas de óbitos por doenças do aparelho circulatório apresentaram relação estatística significativa com a concentração atmosférica de PM_{10}. No

segundo artigo analisaram-se os focos de calor registrados pelo Instituto Nacional de Pesquisa Espacial - INPE, provenientes de queimadas na área rural e urbana do município de Piracicaba-SP, e sua correlação com a concentração atmosférica de material particulado inalável urbano e óbitos por doenças do aparelho circulatório e respiratório, dispondo a freqüência dos óbitos e focos de calor em um SIG – Sistema de Informação Geográfica, por meio do sistema ArcGIS 9.2. Os resultados apontaram um total de 255 focos de queimada para o ano de 2007, com a presença de correlação estatisticamente significativa entre o número de focos de queimada e a concentração atmosférica de material particulado. A freqüência e disposição dos óbitos foram maiores nos bairros centrais e mais povoados da cidade, contudo, a taxa de mortalidade específica foi maior nos bairros periféricos, mais suscetível à poluição e às variáveis socioeconômicas. Pode-se concluir no presente estudo que a maior parte dos focos de calor registrados pelo INPE ocorreu entre os meses de maio e outubro, coincidente com safra da cana-de-açúcar e com os registros mais elevados da concentração atmosférica do material particulado no município. Em relação aos óbitos, é necessário que outros estudos levem em consideração as variáveis sociais e econômicas das populações expostas ao poluente.

Palavras-chave: Mortalidade, Poluição do Ar, Material Particulado, Sistema de Informações Geográficas.

GENERAL SUMMARY

Countless studies point to associations between events of air pollution and increase in mortality from diseases of the circulatory and respiratory systems. The city of Piracicaba-SP is considered a center of national industrial production relying on steel industries and sugarcane and alcohol mills that require extensive crops of sugarcane in which is commonly employed the use of fire prior to harvesting, generating thus, an excessive production of particulate matter. This study aims to evaluate the association between deaths from diseases of the circulatory and respiratory systems, and atmospheric concentrations of inhalable particulate matter pollution in 10ìm in diameter (PM_{10}). This work was divided in two articles of epidemiological research carried out in Piracicaba-SP. The first article analyzed the statistical association between variables such as atmospheric concentration of inhalable particulate matter and urban deaths from circulatory and respiratory diseases, adjusted for seasonality: relative humidity and temperature. The results showed a statistically significant correlation between relative humidity and atmospheric concentration of particulate matter, and a weak correlation for deaths from diseases of circulatory system and air concentrations of particulate matter - RR: 1.006 (1,002-1,010) - demonstrating that interquartile variations in the concentration of the pollutant generate increases in death rates from diseases of the circulatory and respiratory systems. It can be concluded that the pollutant particulate matter is inversely correlated with the seasonal variable relative humidity, and the rates of deaths from diseases of circulatory system showed statistically significant relationship with the atmospheric concentration of PM_{10}. The second article, examined the hotspots reported by the Space Research National Institute - INPE, from fires in rural and urban area of Piracicaba-SP, and its correlation with the atmospheric

concentration of inhalable urban particulate matter and deaths from disease of circulatory and respiratory systems, providing the frequency of death and hotspots in a GIS - Geographic Information System, by the ArcGIS 9.2. The results showed a total of 255 outbreaks of fire for the year 2007, with the presence of a statistically significant correlation between the number of outbreaks of fire and atmospheric concentration of particulate matter. The deaths frequency and distribution were higher in the central and most populous districts, however, the specific mortality rate was higher in the peripheral suburbs, more susceptible to pollution and socioeconomic variables. It can be concluded by this study that most hotspots reported by INPE occurred between May and October, coinciding with the sugarcane harvesting season and the highest records of material particulate atmospheric concentration in the municipality. Concerning the mortality rates, other studies are necessary taking into account social and economic variables of the populations exposed to these risks.

Keywords: Mortality, Air Pollution, Particulate Matter, Geographic Information System.

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INTRODUÇÃO

Inúmeros estudos nacionais e internacionais reportam a associação entre episódios agudos de poluição do ar atmosférico e a ocorrência de óbitos e internações hospitalares por doenças do sistema circulatório e respiratório. O caso de Londres em 1952, registrou um incremento de aproximadamente 4.000 óbitos em função da poluição atmosférica aguda, fato este que despertou a atenção mundial para a importância do controle à poluição atmosférica. Em todos estes casos de poluição citados pela literatura, o material particulado inalável ($PM_{10\mu m}$) foi considerado o maior causador de efeitos deletérios à saúde humana (Freitas *et al.*, 2004).

O material particulado inalável é um dos principais poluentes responsáveis pelas causas de óbitos e internações hospitalares descritos pela literatura e, em geral, é dividido em três tipos de partículas de acordo com a medida de seu diâmetro em micrômetros: grossa ($PM_{10\mu m}$), fina ($PM_{2,5\mu m}$) e ultrafina ($PM_{0,1\mu m}$), sendo que estas duas últimas, possuem a capacidade de penetrar pelas vias aéreas e atingir as porções mais profundas do sistema respiratório, por isso são também chamadas de partículas respiráveis, desencadeando reações inflamatórias nos alvéolos pulmonares (Arbex *et al.*, 2004).

Um estudo ecológico realizado na cidade de São Paulo, buscando verificar a associação de poluentes atmosféricos e seus agravos à saúde humana, concluiu que existe uma relação estatisticamente significativa entre o aumento no nível de poluentes atmosféricos e o aumento do Risco Relativo (RR) para hospitalizações e óbitos por doenças do aparelho circulatório e respiratório (Gouveia *et al.*, 2006).

Os efeitos da poluição atmosférica oriunda da queima de biomassa também foram estudados por Franco (1992) e percebeu-se que a maioria das pessoas residentes próximas às zonas produtoras de cana-de-açúcar, onde o uso do fogo nas lavouras é comum, demandam um número maior de consultas médicas, atendimentos ambulatoriais, medicação e internações. Thurson (1997) considera que para cada 75 mortes causadas pela poluição atmosférica, têm-se 265 internações por asma, 240 por outras doenças respiratórias, 3.500 idas aos serviços de urgência, 180.000 exacerbações de asma e 930.000 dias com restrições de atividades.

Confirmando tais achados, Dossing (1994), em estudo de caso-controle realizado em âmbito hospitalar, demonstrou que indivíduos expostos à fumaça proveniente da combustão de biomassa apresentam, com mais frequência, quadros de obstrução ao fluxo aéreo quando comparados a grupos não expostos.

Dawud (1999), em estudo epidemiológico retrospectivo realizado na Indonésia, após um incêndio florestal que durou aproximadamente dois meses e resultou em um episódio de poluição aguda do ar atmosférico, com amplo impacto sobre a saúde da população regional, registrou, segundo dados da Secretaria Central de Estatística da Indonésia, um aumento nos atendimentos por asma brônquica, bronquite crônica e infecção respiratória aguda; chegando à cifra de 1.802.340 casos atendidos. Tal evento motivou 36.462 visitas ao pronto socorro, 15.822 internações e 2.446.352 dias de trabalho perdidos.

Em Cingapura, país vizinho à Indonésia, este mesmo evento citado anteriormente, levou a um aumento de 30% nos atendimentos ambulatoriais relacionados a patologias respiratórias, sendo que o aumento nos níveis de material particulado foi significativamente

associado a um aumento nos casos de infecção respiratória aguda, asma e rinite (Brauer & Hisham, 1998). Heil (2001) estimou os gastos extras com saúde em decorrência deste incêndio que atingiu a Indonésia e países vizinhos, de cerca de 4,5 bilhões de dólares, fato este que despertou a atenção de autoridades sanitárias em todo o mundo.

De posse destes dados, alguns países criaram suas agências de monitoramento e controle da qualidade do ar, entre eles podemos citar: Estados Unidos e Inglaterra. No Brasil, o Estado de São Paulo conta com a Companhia de Tecnologia e Saneamento Ambiental (CETESB) que possui várias estações de monitoramento da qualidade do ar, uma vez que este Estado comporta o maior pólo industrial do país e é também o maior produtor nacional de cana-de-açúcar.

Os padrões de qualidade do ar propostos pela Agência de Proteção Ambiental Americana apontam o nível médio aritmético de concentração anual aceitável para o material particulado inalável em cerca de 50 $\mu g/m^3$ de ar atmosférico, e o nível limite máximo diário para 24 horas em 150 $\mu g/m^3$ (Cançado *et al.*, 2006). Relatórios emitidos pela CETESB, datados de 1986 e 1999, mostram um importante aumento de material particulado inalável (PM_{10}) no Estado de São Paulo no período da safra da cana-de-açúcar quando comparados ao período de entressafra (CETESB, 1986; CETESB, 1999).

Zancul (1998) quantificou a emissão de material particulado na região metropolitana de São Paulo por veículos automotivos em aproximadamente 62 toneladas/dia, ao passo que o material particulado proveniente da queima da biomassa da cana-de-açúcar pode chegar a 285 toneladas/dia em regiões onde esta prática é comum. Zhang & Smith (2007), em estudo epidemiológico conduzido na China, concluíram que a

utilização da queima da biomassa como fonte de energia, gera um forte impacto na saúde da população exposta a este evento, dentre os quais cita: câncer de pulmão, doenças respiratórias, infecções respiratórias agudas, doença pulmonar obstrutiva crônica e comprometimento do sistema imunológico.

Visando reduzir a emissão de material particulado, o governo do Estado de São Paulo publicou em março de 2003, a lei nº 11.241 que dispõe sobre a eliminação do uso do fogo nas lavouras de cana-de-açúcar, porém, o prazo estipulado para o fim dessa prática se estende até o ano de 2031 (Lopes & Ribeiro, 2006). Esta lei está sendo revista para redução do prazo acima estipulado pelo Governo do Estado através do protocolo agroambiental, abolindo o uso do fogo nas lavouras de cana-de-açúcar em 2017.

Em uma revisão sistemática realizada pelas Nações Unidas, utilizando-se de estudos populacionais, amparados por estudos em animais, concluiu-se que a exposição à poluentes do ar no período intrauterino e pós-natal podem levar a distúrbios de crescimento pulmonar e aumentam significativamente os riscos de contrair infecções respiratórias no período pós–natal (WHO, 2005; Bittar, 2008).

Outro estudo conduzido em seis cidades européias por Ruckerl *et al.,* (2007), com pacientes cardiopatas, detectou uma associação positiva para o aumento da concentração de partículas atmosféricas e o aumento dos níveis plasmáticos de interleucina 6 (IL-6), observando-se o efeito destes poluentes no organismo humano em um intervalo de tempo de 12 a 17 horas após a exposição dos pacientes ao aumento da concentração destes poluentes (denominado “efeito colheita”); havendo também uma associação positiva entre o

aumento de PM_{10} atmosférico e os níveis de fibrinogênio no plasma sanguíneo destes pacientes.

PROPOSIÇÃO

O presente estudo foi realizado em formato alternativo conforme deliberação da Comissão Central de Pós-Graduação (CCPG) da Universidade Estadual de Campinas – UNICAMP n°001/98 e foi composto por 2 capítulos, cujos objetivos são:

CAPÍTULO 1: Verificar a associação entre a variação interquartil da concentração atmosférica de material particulado inalável (PM_{10}) e os incrementos gerados nas taxas de óbitos por doenças dos aparelhos circulatório e respiratório no município de Piracicaba-SP, para o ano de 2007, levando em consideração as variáveis de confusão umidade relativa do ar e temperatura.

CAPÍTULO 2: Analisar a correlação entre focos de calor detectados por satélites do INPE – Instituto Nacional de Pesquisas Espaciais, provenientes de queimadas nas áreas rural e urbana do município de Piracicaba-SP, a concentração atmosférica do poluente material particulado inalável (PM_{10}), e seu impacto sobre a distribuição espacial de óbitos por doenças dos aparelhos circulatório e respiratório em função das zonas de adensamento de poluição dispostas em um SIG – Sistema de Informação Geográfica.

CAPÍTULO 1

Association between particulate matter and mortality from respiratory and cardiovascular diseases in the municipality of Piracicaba, Brazil: Ecological Study

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Key-words: Mortality, Air Pollution, Particulate Matter, Respiratory and Circulatory Disease.

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We declare no competing interest among authors in this present study.

Abbreviations

PM – Particulate Matter

RH – Relative Humidity

MCD – Mortality Circulatory Disease

MRD – Mortality Respiratory Disease

Temp - Temperature

ABSTRACT

Background: *Several studies have associated the percentile variation of particulate matter air pollution and cardio-respiratory mortality.*

Objective*: to analyze the association between atmospheric particulate matter concentration and increasing mortality rates for cardio-respiratory diseases, in the municipality of Piracicaba.*

Material and Methods*: This ecological study took into account weekly measure of atmospheric particulate matter concentration and rates of circulatory and respiratory mortality in a 3-day lag-structure adjusted for seasonality. Data were treated by Chi-square, Pearson's Correlation, and Negative Binomial Distribution.*

Results*: A high correlation was found between the variables* PM_{10} *and humidity, and the variables cardiovascular mortality and* PM_{10} *presented a weak correlation. Interquartile Range (IQR) of pollutant variation (25%-75%) was significantly associated with mortalities from circulatory - RR: 1,006 (1,002-1,010) and respiratory diseases - RR: 1,005 (0,999-1,011).*

Conclusion*: These findings indicate variations in air pollutant concentration might lead to increasing mortality rates from circulatory and respiratory disease influenced directly by seasonality and weather conditions*

BACKGROUND

For over 50 years, acute episodes of air pollution have been reported in the medical literature in several countries, such as England, France, United States, some from fires, others from weather phenomena such as thermal inversion, which were all associated with adverse effects on human health, producing a strong impact on mortality rates (Davis et al. 2004; Cançado et al. 2006; Wong et al. 2008; Breitner et al. 2009).

Biomass burning has been present in human civilization since the Stone Age and is considered one of the first sources of anthropogenic atmospheric pollution. Scientific advances have generated new sources of pollutants, such as the burning of fossil fuels and emission of pollutants from industrial production, emitting inhalable particulate matter ($PM_{10\mu m}$) that increases mortality rates, hospital admissions, emergency room visits, demand for drugs, decreased lung function and life expectancy (Arbex et al. 2004; Cançado et al. 2006; Ebi and McGregor, 2008, Huang et al. 2009, Pope et al. 2009).

Numerous studies have found a significant association between daily levels of air pollution by inhalable particulate matter (PM_{10}) with hospitalizations and deaths from respiratory and circulatory diseases, and the commitment of weight gain during pregnancy and intrauterine growth retardation-IUGR (Dejmek et al. 2000; Maisonet et al. 2001; Davis et al. 2004, Medeiros and Gouveia, 2005, Gouveia et al. 2006; Samoli et al. 2008; Breitner et al. 2009; Liang et al. 2009).

The inhalable particulate matter PM_{10} presents a lag between exposure and damage to health increasing the risk of deaths from circulatory diseases, especially acute myocardial infarction due to increased production of fibrinogen, and viscosity of blood

plasma (Kodavanti et al. 2003; Gouveia et al. 2006, Martins et al. 2006; Puett et al. 2008; Buadong et al. 2009, Floyd et al. 2009).

Studies show that for every increase of $10\mu g/m^3$ in the atmospheric concentration of inhalable particulate matter, there are variations in the proportional mortality per day (Gouveia et al. 2006; Puett et. Al. 2008; Wong et al. 2008; Huang et al. 2009). It is estimated that the reduction in atmospheric concentrations of fine particulate matter ($PM_{2,5}$) to a level of 15 mg/m^3 would reduce the occurrence of premature deaths and increase life expectancy by up to 2 years in cities such as Rome, Bucharest and Tel Aviv (Orru et al. 2009).

The city of Piracicaba has many sources of particulate matter, and is considered a major sugar-cane production center in the State of São Paulo with an area of approximately 50,767 hectares (Brazil, 2009), which uses the practice of crop burning prior to harvesting. The city is home to several steel industries, and also has a large fleet of vehicles. Thus, the aim of this study was to analyze the association between deaths due to circulatory and respiratory systems associated with the concentration of airborne particulate matter adjusted for seasonal variations in this county for the year 2007.

MATERIAL AND METHODS

The study of an ecological nature was conducted in the city of Piracicaba, located at 22 º 43'31" south latitude and 47 º 38'57" west longitude at an altitude of 547 meters. In 2007 it had a population of 358,108 inhabitants, with an estimated GDP of 5.7 billion (IBGE, 2008). This research used secondary data from the Piracicaba Health Department,

Luiz de Queiroz Superior School of Agriculture - ESALQ and Company of Technology and Environmental Sanitation - CETESB.

Deaths due to diseases of the circulatory and respiratory systems were provided by the Department of Epidemiological Surveillance of the City of Piracicaba, with daily attendance records of deaths during the year of 2007, which is consistent with the 10th revision of International Classification of Diseases - ICD X, addressing the chapters X - Respiratory Diseases and IX - Diseases of the circulatory system. The data took into account only deaths from natural causes, with no predilection for age, sex, creed or race, obeying a lag structure of 3 days (lag 0-72h) between the measurement of atmospheric concentration of the pollutant taken every Monday and death events collected ever since.

Data on air pollution were obtained from CETESB (2007), and come from a manual station weekly monitoring air quality for particulate matter 10 microns ($PM_{10\mu m}$) in diameter. The sampling is performed for 24 hours every 6 days of the month. These data were collected from the company's website, and these records are available for public consultation.

The seasonal data were collected on the website of the Department of Mathematical Sciences, School of Agriculture Luiz de Queiroz - ESALQ / USP from an automatic weather station that produces the daily measurement of temperature and Relative Humidity (RH), located within university campus, in the urban area. The weekly average was calculated for statistical purposes.

Statistical data analysis was performed by Pearson's correlation between independent variables and descriptive statistics. The Value of "deviance" and the statistical

chi-square test were used to assess whether there was over- or Underdispersion of data. A negative binomial model was used and the fit of the model was assessed by the Log Likelihood.

RESULTS

A total of 770 deaths from cardiovascular and respiratory diseases was recorded by the local authorities for the 2007 year in the city of Piracicaba, with a monthly average of 40.4 (DS : ± 7.5) for cardiovascular diseases and 23.7 (DS: ± 8.2) for respiratory diseases, as shown in Figure 1.

The meteorological variables and pollutants also presented monthly fluctuations. Particulate matter showed a monthly average of 45.5 mg/m^3 (DS: ± 25.1) as shown in Figure 2. The months of August and September showed the highest atmospheric concentration rates when compared with the other months of the year, registering 91.2 mg/m^3 and 88.4 mg/m^3 respectively of the pollutant. The lowest concentrations of PM_{10} were in January and December with atmospheric concentrations at 17.6 mg/m^3 and 20.6 mg/m^3 respectively.

As regards humidity, the months of January and May were the wettest, with a percentage of 94.42 and 87.44 respectively. September and October are considered the driest, with percentages of 66.16 and 70.84, recording a monthly average of 82.8 (DS: ± 7.9). The temperature also fluctuated with the highest averages shown for February and March (24.62 ° *C and 24.9 ° C). June and July were the coldest (18.3 ° C and 17.48 ° C)* and the monthly mean was 21.8 ° *C (DS: ± 2.5).*

The coefficients of correlation between the air pollutant, climatic variables and mortality are shown in Table 1. It may be noted that the variables PM_{10} and R.H showed a significant correlation, while the variables mortality from circulatory disease and PM_{10} showed weak correlation. No significant correlation was found between the other variables.

With regard to the interquartile variation in the atmospheric concentration of particulate matter it can be observed that this resulted in a simultaneous increase in the rates of death due to circulatory and respiratory systems.

The descriptive statistics of the dependent variables (deaths from circulatory diseases and deaths from respiratory diseases) and independent, particulate matter and meteorological (relative humidity and temperature) are shown in Table 2.

From the value of statistical deviation and chi-square test it is noted that the Negative Binomial model is appropriate to describe such data, since it had the diversion of 65.62 with 56DF for mortalities due to circulatory diseases, and 73.19 with 56DF for respiratory disease with factor K = 1.1719 and 1.3071, respectively, as described below in Table 3.

Interquartile variations (25-75percentil) in the pollutant concentration resulted in increasing rates of mortality from circulatory and respiratory diseases. The measure of relative risk (RR) and the respective confidence intervals are presented in Table 4. The variable PM_{10} was significantly associated with deaths from circulatory diseases (RR = 1.006, 95% :1,002-1, 010), while the other variables presented no statistically significant association.

DISCUSSION

The effects of seasonality shown in this study were similar to those reported by Liang et al. (2009), in which the greatest variations of particulate matter were observed during winter and were accompanied by higher frequencies of deaths, thus showing a greater impact of the interquartile range of pollutant and deaths for this season.

The statistical results showed the presence of an inverse correlation between PM10 and URA, observed especially for the month of January, when there was a lower concentration of PM10, and most of the year of URA (17.6 mg/m^3 and 94.42), respectively. Conversely, the month of September, considered the driest month of the year, recorded the second highest average of the pollutant for the year 2007, with 66.16 and 88.4 mg/m^3 for PM_{10} and concentration of URA, respectively. This inverse correlation between PM_{10} and URA was also found in the study by Davis et al. (2004).

In an ecological study conducted by Wong et al. (2008), in 4 Chinese cities, the ratio of deaths from cardiovascular diseases in comparison with the respiratory system were of 4:1 in Wuhan, 3-1 in Shanghai, Bangkok and 2:1, 1.5:1 in Hong Kong. In the present study the relationship between deaths was 1.7:1.

In this study, the relative risk for interquartile changes of pollutant-related death, was RR = 1.006 (1,002-1,010) for circulatory diseases, and RR = 1.005 (0,999-1,011) for respiratory diseases and was statistically significant only for diseases of the circulatory system, as seen in the study of Huang et al. (2009). However, in the study by Liang et al. (2009), the relative risk for deaths due to diseases of the circulatory and respiratory changes associated with interquartile PM_{10} was 1.12 (0.998-1.258) and 1.194 (1002-1425), respectively, being statistically significant only for respiratory deaths.

The interquartile range of the particulate matter increases in deaths registered for diseases of the circulatory and respiratory diseases, similar to the study of Wong et al. (2008), in which these values were estimated to be 0.4% and 0.6%, respectively, indicating a major complication of deaths from respiratory diseases when compared with this study.

Among the confounding factors mentioned in the literature, it is believed that populations exposed to "outdoor" environments suffer more from the effects of the pollutant studied, due to greater exposure to it. Another important factor is the frequency of air currents in the localities under study, with the potential to disperse the pollutants, the oscillations of pressure and temperature, especially the highest, are factors that favor the occurrence of episodes of air pollution. One must also consider that the effect of interaction of the pollutant under study with other air pollutants (NO_2, CO_2, O_3, SO_2) were not measured in this study, which interferes with the results of the generalized additive factors (Davis et al., 2004, Wong et al., 2008; Ebi and McGregor, 2008).

As regards temperature, Basu (2009) claimed that elevated temperature is associated with increased risk for those dying from cardiovascular, respiratory, cerebrovascular, and some specific cardiovascular diseases; showing that a 1 ˚*C increase in temperature* correspond to 3,12% increase in daily mortality in cities in the Mediterranean region and Korea. However, in this present study, the mean temperature (21.8 ˚ *C)* showed no association with mortality rates, and was lower when compared with the Mediterranean (29.4 ˚ *C) and Korea (29.7 ˚ C) means, even when adjusted for pollutants.*

The annual average concentration of particulate matter found in this study was 45.6 mg/m^3, indicating a reduction of this pollutant in the city of Piracicaba-SP, when compared

with data collected by Cançado et al. (2006), showing the average annual $56 \mu g/m^3$ for data collected between the years 1997 to 1998.

It is prudent to note that Resolution No. 03/90 CONAMA - National Council of Environment, set the primary standard of maximum annual average atmospheric air quality *concentration of* $50 \mu g/m^3$ and as a secondary standard the average daily maximum $150 \mu g/m^3$ should not be exceeded more than once a year (CETESB, 2008). In this study, it could be observed that the annual average was below the value established by CONAMA, however, the maximum daily recorded in this study in the month of September was $154 \mu g/m^3$.

CONCLUSION

In conclusion, a statistically significant association was found between interquartile variations in the atmospheric concentration of inhalable particulate matter and deaths from circulatory diseases. In this study, deaths from circulatory diseases were more affected by variations in atmospheric pollutant when compared with deaths from respiratory diseases.

The studied pollutant showed an inverse correlation with the seasonal variable relative humidity. Although values above the maximum levels accepted by the law of CONAMA were recorded, the study found an improvement in air quality in the city of Piracicaba-SP, when compared with the results of previous studies.

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Table 1. Pearson's Chi-Square Test among variables of PM_{10}, Relative Humidity, Temperature, Mortality from Circulatory and Respiratory disease.

	PM_{10}	M.C.D	M.R.D	R.H	Temp.
PM_{10}	1,000				
M.C.Disease	0,296*	1,000			
M.R.Disease	$0,104^{ns}$	$0,062^{ns}$	1,00		
R.H	-0,555**	$0,006^{ns}$	$0,141^{ns}$	1,00	
Temp.	$-0,035^{ns}$	$-0,137^{ns}$	$-0,321^{ns}$	$-0,212^{ns}$	1,00

* ($p<0,05$), ** ($p<0,01$), ns (non significant)

Table 2. Descriptive Data of PM_{10}, M.C.D., M.R.D., R.H and Temperature.

Paremeters	Monthly Mean	S.D	Minimum Value	25%	50%	75%	Maximum Value
PM_{10}	45,62	25,15	4,00	21,00	34,5	65,00	154,00
M.C.D	40,43	7,50	0,00	3,00	4,5	6,00	11,00
M.R.D	23,72	8,20	0,00	1,00	2,00	3,00	7,00
R.H	82,81	7,93	59,1	75,45	83,70	90,20	99,9
Temp.	21,83	2,52	11,9	19,75	22,90	23,90	26,5

S.D = Standard Deviation

Table 3. Goodness criteria for Negative Binomial adjust.

Variable	Criteria	DF	Value	Value/DF
M.C.D	Deviance	56	65,62	1,1719
	Pearson Chi-square	56	61,42	1,0967
M.R.D	Deviance	56	73,19	1,3071
	Pearson Chi-square	56	59,99	1,0714

Table 4. Relative Risk (RR) e Confidence Interval (CI 95%) for Mortality from Circulatory and Respiratory Disease by Negative Binomial Distribution.

Mortality		RR	IC 95%	
			Lo. Lim.	Up. Lim.
M.C.D	PM_{10}	1,006	1,002	1,010
	Humidity	1,011	0,996	1,026
	Temperature	0,988	0,949	1,028
M.R.D	PM_{10}	1,005	0,999	1,011
	Humidity	1,015	0,993	1,038
	Temperature	0,943	0,894	0,996

Figure 1: Seasonal distribution of deaths from circulatory and respiratory diseases for the year 2007. Source: Piracicaba Public Health Department.

Figure 2: Distribution of variables of PM_{10}, Relative Humidity (RH) and temperature for the year of 2007. Source: ESALQ, 2008.

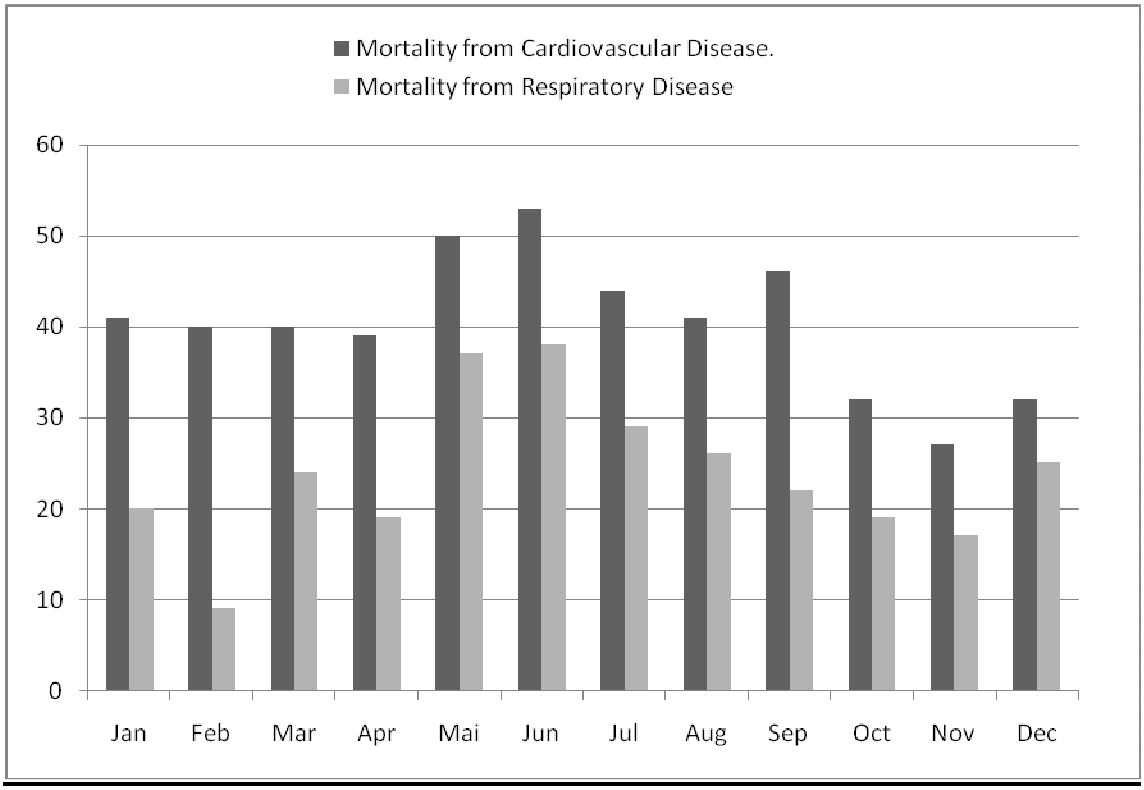

Figure 1

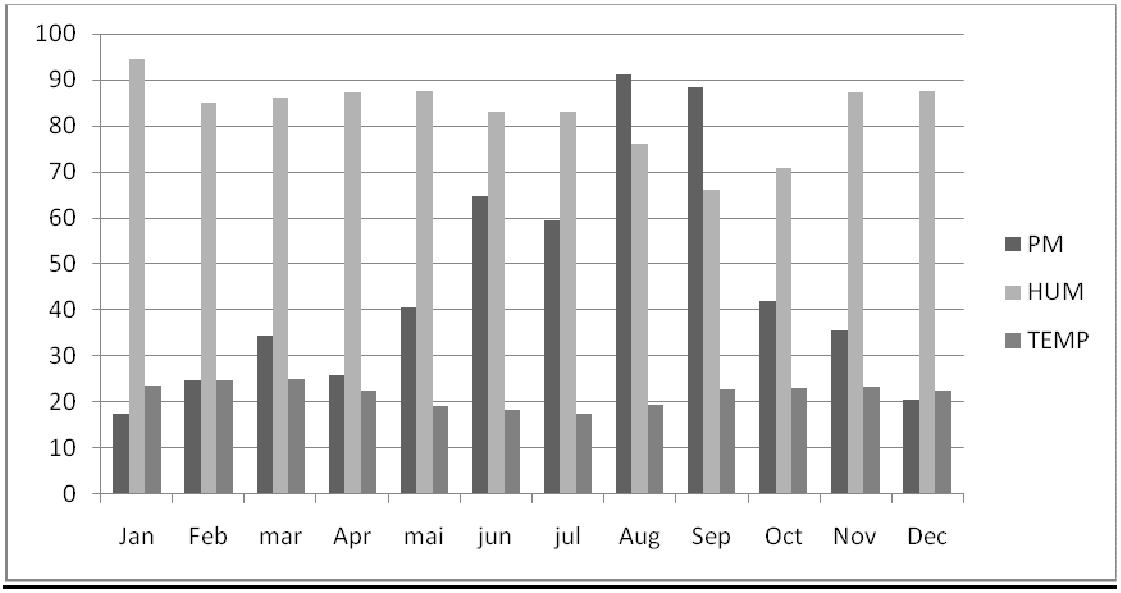

Figure 2

CAPÍTULO 2

Spatial Distribution of Mortality Index and Its Correlation with Fire Hotspots in the Municipality of Piracicaba-SP, Brazil

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ABSTRACT

Objectives*: To analyze the correlation between fire hotspots and atmospheric concentration of inhalable particulate matter pollution, and spatial distribution of mortality from circulatory and respiratory diseases.*

Methods*: All the fire hotspots in Piracicaba were mapped during the year 2007, and the weekly concentrations of inhalable particulate matter (PM_{10}) were analyzed. Thematic maps were constructed using ArcGIS 9.2 software and geo-referenced to the SAD 69 system. Mortality data were gathered from local public health agency per neighborhood, considering 62 suburbs in the entire city. The data were treated statistically using Pearson's correlation.*

Results*: 255 hotspots were found, showing a higher frequency for the period from May to October, mostly in the rural perimeter, reaching non-forest areas, and a highly significant correlation with atmospheric concentration of inhalable particulate matter ($p = 0.0003$). The districts most affected by the pollution did not record the highest death rates according to population density.*

Conclusion*: The majority of hotspots reported in this study coincided with the sugarcane crop harvesting period, and although there was a highly significant correlation between the number of fire hotspots and atmospheric concentration of particulate matter, there is a need to take into account the velocity and direction of air currents and socioeconomic variables to avoid bias.*

Keywords: Geographic Information System, Mortality, Air Pollution.

INTRODUCTION

The need to establish links between health issues and geographical space, coupled with the evolution of computer graphics resources, has contributed to the development of Geographical Information System - GIS applications in health, with particular attention to the areas of surveillance, evaluation of health services and urbanization and environment (Lopes, 2005).

The use of spatial distribution of health events has been common practice around the world, and examples may be mentioned, such as the mapping of hospital admissions in Brazil associated with events of air pollution (Lopes & Ribeiro, 2006); association between fresh water availability, sanitation and the occurrence of diarrheal infection in India (Gopal et al., 2008), spatial distribution of epidemic diarrhea in Thailand (Chaikaew et al., 2009); dengue in Nicaragua (Chang et al., 2009); communicable diseases in Canada (Dravicevic & Perez, 2009), mortality associated with air pollutants in Australia (Wang et al., 2009), pregnancy and adolescence in Brazil (Nogueira et al, 2009), Risk of Rift Valley Fever (RVF) by infestation of Aedes vexans in Senegal (Vignolles et al., 2009), risk of malaria in Colombia (Rincón-Romero and Londoño, 2009).

The State of Sao Paulo is at present one of the largest producers of sugarcane in the country with an area of about 2 million hectares, and mechanized harvesting occurs in only 25% of this area, the remaining 75 % being cut manually, in which fire is used to drive away poisonous animals and facilitate the work of harvesting done by productors laborers (Lopes, 2005).

This practice of burning crop trash (straw) prior to harvesting produces a huge amount of air pollutants, especially the inhalable particulate matter (PM_{10}). Zancul (1998) claims that in an acreage equivalent to 8.2% of the State of Sao Paulo, 285 tons of particulate matter per day are produced, i.e., four times more pollution than the amount produced by the metropolitan region of Sao Paulo, thus generating public health problems, such as increased rates of mortality, hospital admissions, emergency visits, among others (Lopes & Ribeiro, 2006).

In this context, the aim of this study was to analyze the distribution of georeferenced data on health in a GIS environment - Geographic Information System, by constructing thematic maps on mortality from diseases of the circulatory and respiratory systems, and outbreaks of fire in Piracicaba, SP, for the year 2007.

MATERIAL AND METHODS

The present ecological study was conducted in the city of Piracicaba, State of Sao Paulo, located at 22 º 43'31 "south latitude and 47 º 38'57" west longitude at an altitude of 547 meters. In 2007, Piracicaba had a population of 358.108 inhabitants, with an estimated GDP of U.S. $ 2.6 billion dollars (IBGE, 2008). This research used secondary data from the National Institute for Space Research (INPE), the Brazilian Institute of Geography and Statistics (IBGE) and the Center of Technology and Environmental Sanitation - CETESB, for the year 2007, seeking to identify a possible association between outbreaks of fire and the deaths from diseases of the circulatory and respiratory systems.

Mortality data from circulatory and respiratory diseases were provided by the local Department of Epidemiological Surveillance, records of daily obituaries registered for the

year 2007, with all deaths(?) referenced in 62 suburbs, displayed in the IBGE map of the city of Piracicaba. Deaths were recorded in accordance with the 10th revision of International Classification of Diseases - ICD-X, covering chapters X - Respiratory Diseases and IX - Diseases of the circulatory system. The data took into account only deaths from natural causes, with no predilection for age, sex or race.

Thematic maps were generated according to the variables adopted in this study, using two different scales in ArcGIS 9.2 software (Environmental System Research Institute, Inc. 1990). The maps relating to hotspots were developed in a standard scale, referenced to the South American Datum system - SAD 69 on a map prepared by IBGE, from the digital net of the State of São Paulo, scale 1:10.000. The scale used to map the distribution of deaths was 1:6.000.

The deaths were arranged on a map, using a range of frequency pointing out the neighborhoods with the highest incidence for both cardiovascular diseases and for respiratory diseases.

For the distribution of hot spots a buffer zone was created, with a radius of 250 meters for each source of heat maps, using the Kernell method to observe the interpolation of the areas most affected by fires, producing a wide range of density focus spots on the city map.

Details of the outbreaks of fire in the municipality of Piracicaba for the year 2007 were obtained from the site of the National Institute for Space Research - INPE, reported by seven different satellites: NOAA-12, NOAA-15, NOAA-17, NOAA -18, GOES-10, AQUA and TERRA.

The variables analyzed in this study were described and treated statistically by Pearson's correlation with the SAS system 8.0, adopting a level of significance of $p < 0.05$.

RESULTS

For the year 2007, 255 outbreaks of fire were recorded and most of them were detected in non-forest vegetation, including foci in the urban area. The largest number of outbreaks was recorded in September, following the sugarcane harvesting period in the region (May-October), as shown in Figure 1.

The results of the Pearson's correlation between the variable fire hotspot and other variables were statistically significant only for the atmospheric concentration of particulate matter (p = 0.0003) with CI = 0.57-0.96 r = 0. 8611, and for deaths from respiratory diseases (p = 0.1822) and deaths from circulatory diseases (p = 0.3370) there was no significant correlation.

Outbreaks of heat coming from Piracicaba were collected from the database using what?, and they were identified and located by latitude, longitude, and then these data were entered into ArcGIS, providing the playback map of the city, geo-referenced with the exact location of hotspots. As shown in Figure 1, only 5.5% (n = 14) hotspots were recorded in urban areas, while 94.5% (n = 241) of the other outbreaks were in rural and peri-urban areas.

In order to observe the density of pollution and the worst-hit areas, a thematic map was set up by the kernel model, displaying a projection buffer with a radius of 250 meters for each focus located about 5 km from the urban perimeter. Through this model, shown in

Figure 3, it was possible to analyze the density of hotspots, and therefore, measure the impact of pollution on the city's neighborhoods. Note that the suburbs were the most affected by the density area of pollution.

There were a total of 485 deaths from cardiovascular diseases and 285 due to diseases of the respiratory system, spread over 62 suburbs of Piracicaba-SP for the year 2007. The frequency of these deaths showed seasonal variations depending on the year, with a monthly average of 40.4 (SD = ± 7.5) for cardiovascular diseases and 23.7 (SD: ± 8.2) for respiratory diseases. The highest frequency of death was recorded in the winter season between June and August and lowest during the spring, between September and November.

Figures 3 and 5 show the frequency distribution of deaths from diseases of the respiratory and circulatory systems for the 62 city districts, pointing towards a higher frequency of deaths in the neighborhoods of the central area and high population density. However, when these values are transformed into specific mortality rates and their coefficients are arranged in a scale, as described in Figures 4 and 6, there was a change in death rate according to the peripheral neighborhoods, pointing towards a positive interference of outbreaks of burning in districts located in the peri-urban perimeter.

DISCUSSION

As described by Lopes (2005), it might be noted that the city of Piracicaba-SP is one of the meso-administrative regions of the State of São Paulo hardest hit by outbreaks of heat from burning in non-forest areas recorded by INPE, together with the meso-regions of Araraquara and Ribeirão Preto.

As described by Cançado et al. (2006), a large proportion of outbreaks of fire occurs in the dry season, especially between the months of May to October, the sugarcane harvesting period. The same can be observed in this study (Figure 1), in which the majority of outbreaks of fire were also recorded in this period.

According Cançado et al. (2006), sugarcane plantations comprise 80% of the entire city land area, and the urban area accounts for only 6% of the size of the municipality, with the remainder occupied by pastures 11% and forest 3%. Of the 255 outbreaks reported in this study, 239 (95.68%) were identified in non-forest vegetation.

Although the area density of heat showed that the city suburbs were the most affected by pollution, when the spatial distribution of deaths was analyzed, the central districts registered the highest frequency of deaths. It is believed that this fact is attributable to the population density.

Although the correlation between hotspots and atmospheric concentration of particulate matter was highly significant, it should be noted that the speed and direction of prevailing air currents and the geographical location of the air quality monitoring station were not taken into account. These factors influence the results of this research, making another approach necessary to confirm these results.

The highest absolute frequencies of death were recorded in the central districts, due to the high population density. However, when the specific mortality rate of 62 suburbs were calculated on the basis of their populations, the distribution of deaths showed a clear change in the presented GIS, involving more intense peripheral suburbs, with their

populations being more affected due to the burning points and local production of particulate matter.

CONCLUSION

This study allowed one to conclude that the majority of reported outbreaks of fire in the city were found between the months of May and October, the period coinciding with the time of sugarcane harvesting. While there was a highly significant correlation between outbreaks of fire and atmospheric concentrations of urban particulate matter, it is necessary to investigate the direction and speed of prevailing air currents and geo-monitoring station air quality in the city.

The suburbs most affected by the area of pollution outbreaks of fire had higher death rates when compared with the central area, which presented the highest population densities and higher absolute frequency of deaths. Further studies must take into account socioeconomic variables in order to avoid research bias.

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LEGENDS, FIGURES AND TABLES

Chart 1 - Annual distribution of average mobile hotspots recorded by using the atmospheric concentration of particulate matter (PM10) for the months of the year 2007.

Figure 1 - Spatial distribution of hotspots reported by INPE and their geographical distribution in rural and urban areas, for the city of Piracicaba, SP, 2007. Source INPE, 2008.

Figure 2 - Distribution of the density of outbreaks of spots/km^2 captured by using its interpolation and the kernel method, with 250m buffer for the city of Piracicaba-SP, 2007.

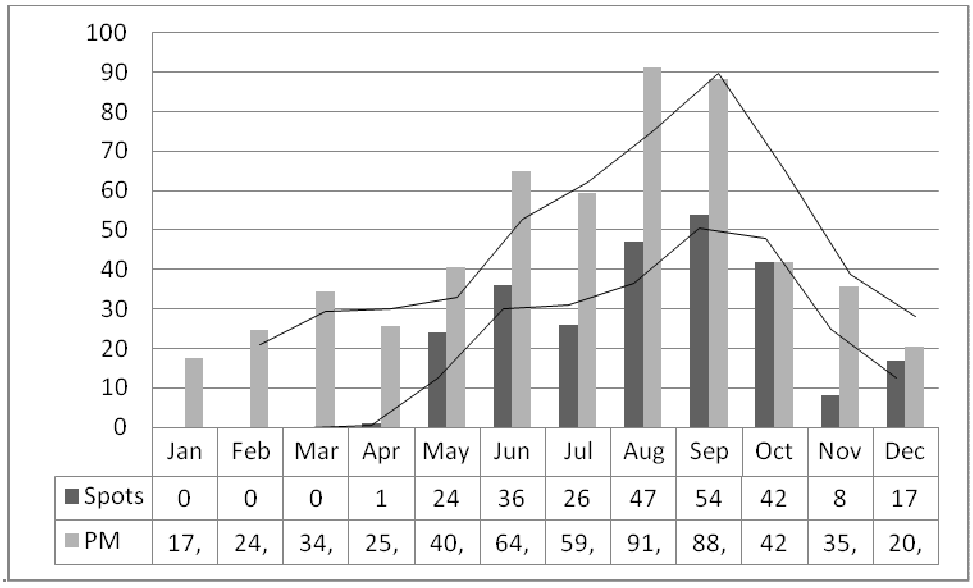
Figure 3 - Spatial distribution of absolute frequency of deaths from communicable respiratory registered in 62 districts of the city of Piracicaba-SP, 2007.

Figure 4 - Spatial distribution of relative frequency of deaths from communicable respiratory tract diseases depending on the specific mortality rate registered in 62 districts of the city of Piracicaba-SP, 2007.

Figure 5 - Spatial distribution of absolute frequency of deaths from circulatory diseases in 62 districts registered in the city of Piracicaba-SP, in 2007.

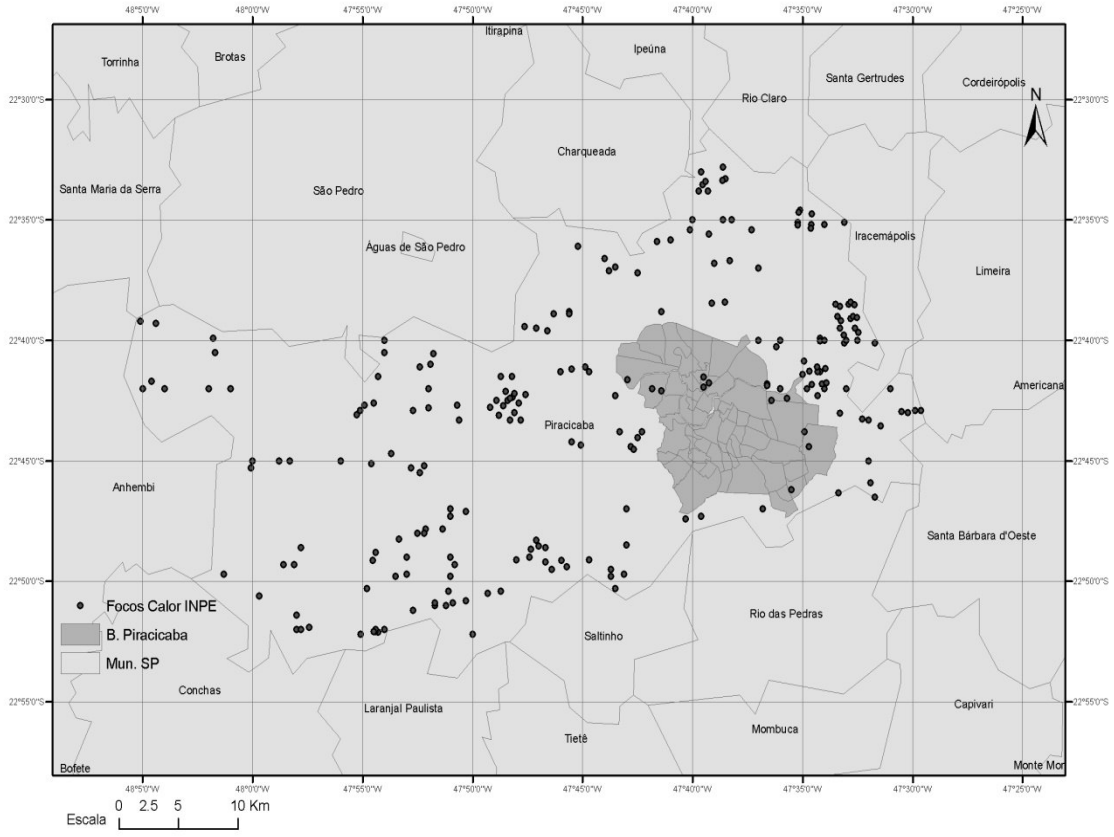
Figure 6 - Spatial distribution of the relative frequency of deaths from circulatory diseases according to the specific mortality rate registered in 62 districts of the city of

Piracicaba-SP, in 2007.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Spots	0	0	0	1	24	36	26	47	54	42	8	17
PM	17,	24,	34,	25,	40,	64,	59,	91,	88,	42	35,	20,

Chart 1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Torrinha
Brotas
Santa Gertrudes
Cordeirópolis
Rio Claro
N
Charqueada
Santa Maria da Serra
São Pedro
Iracemápolis
Águas de São Pedro
Limeira
Americana
Piracicaba
Anhembi
Santa Bárbara d'Oeste
Focos Calor INPE
B. Piracicaba
Mun. SP
Rio das Pedras
Saltinho
Conchas
Laranjal Paulista
Capivari
Mombuca
Tietê
Bofete
Monte Mor
Escala
0 2.5 5 10 Km

Figure 1

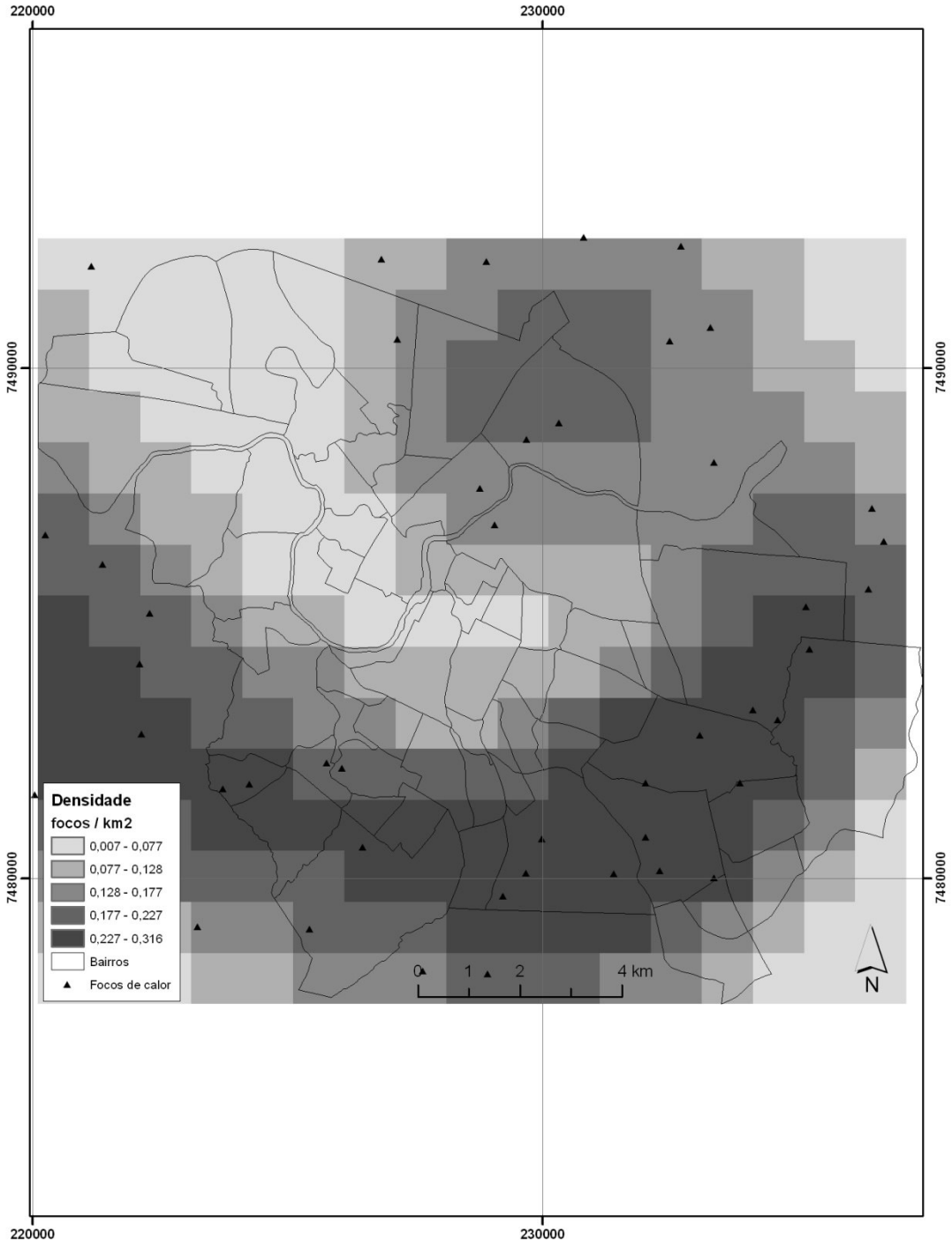
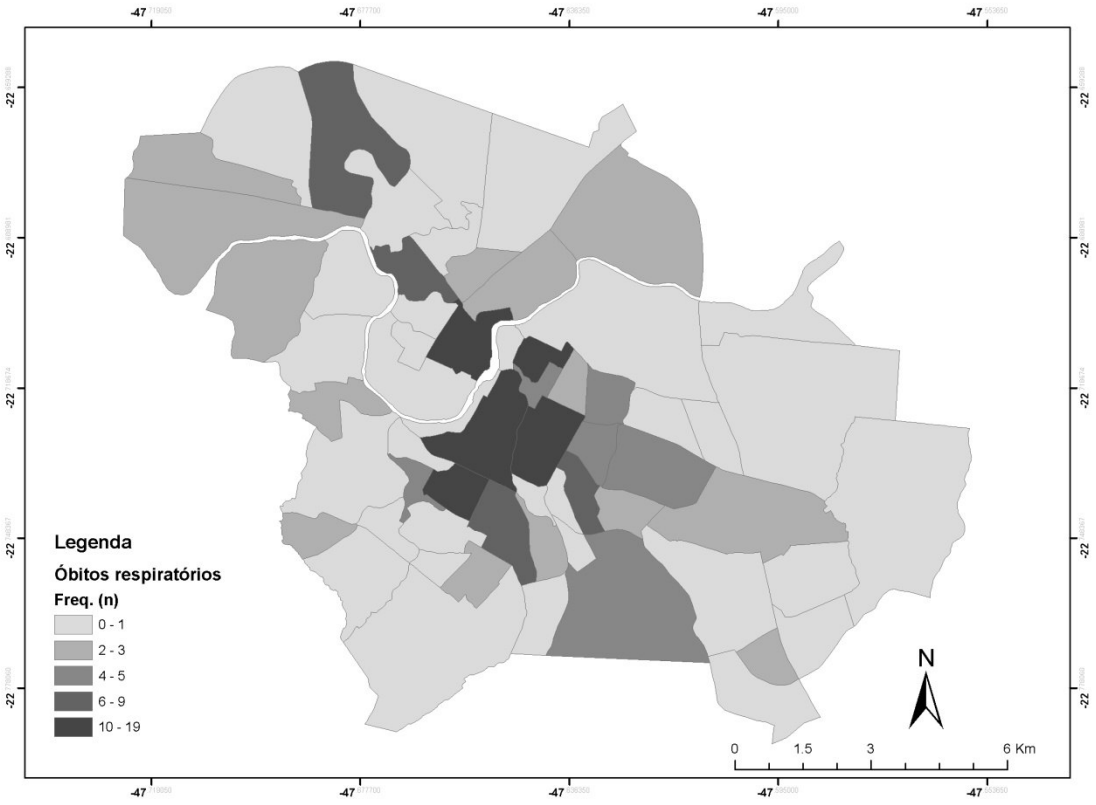

220000
230000
7490000
7480000
Densidade
focos / km2
0,007 - 0,077
0,077 - 0,128
0,128 - 0,177
0,177 - 0,227
0,227 - 0,316
Bairros
Focos de calor
0
1
2
4 km
N

Figure 2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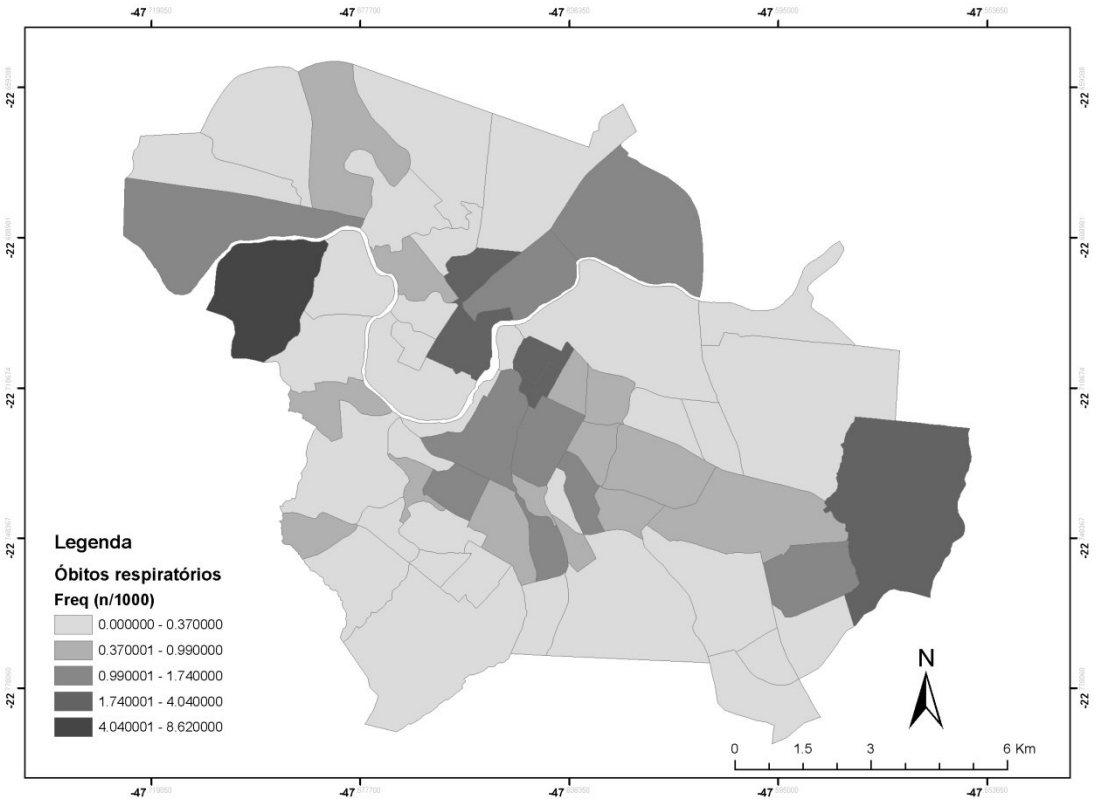
-47 636350
-47 595000
-47 553650
-22 955538
-22 915981
-22 876424
-22 836867
-22 797310
Legenda
Óbitos respiratórios
Freq. (n)
0 - 1
2 - 3
4 - 5
6 - 9
10 - 19
N
0
1.5
3
6 Km

Figure 3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-22 595538
-22 635981
-22 676424
-22 716867
-22 757310
Legenda
Óbitos respiratórios
Freq (n/1000)
0.000000 - 0.370000
0.370001 - 0.990000
0.990001 - 1.740000
1.740001 - 4.040000
4.040001 - 8.620000
N
0
1.5
3
6 Km

Figure 4

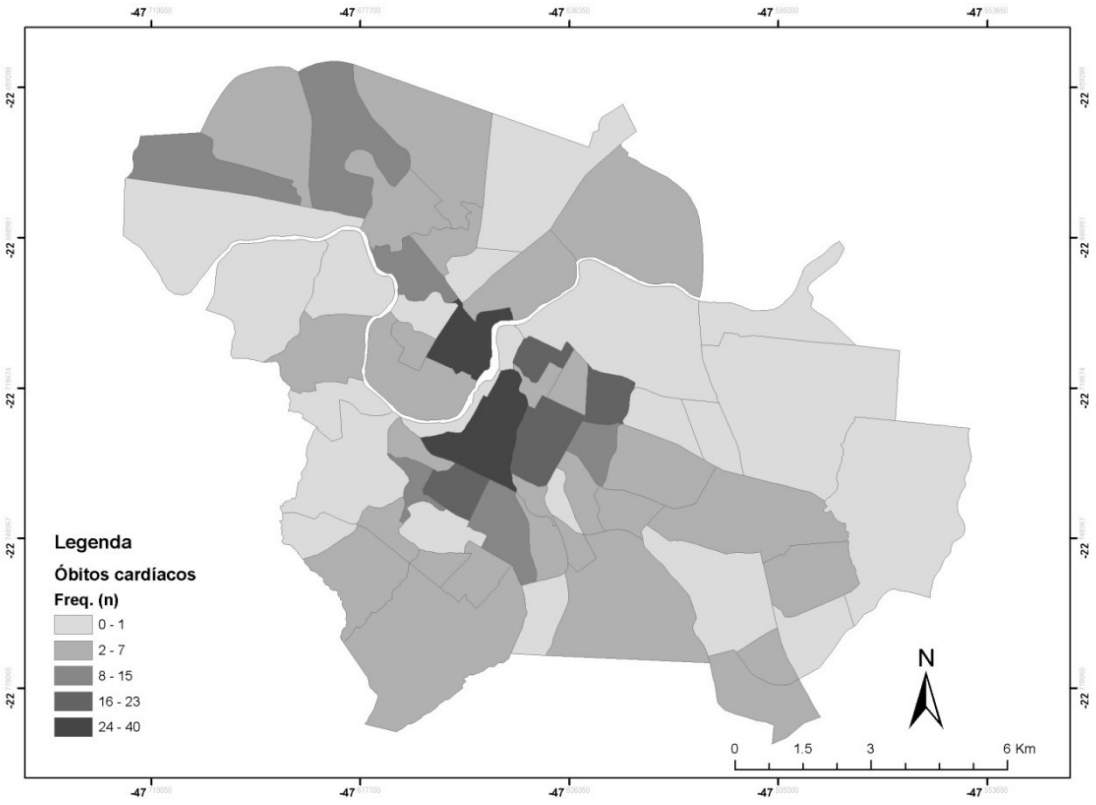
-47
-22
Legenda
Óbitos cardíacos
Freq. (n)
0 - 1
2 - 7
8 - 15
16 - 23
24 - 40
N
0
1.5
3
6 Km

Figure 5

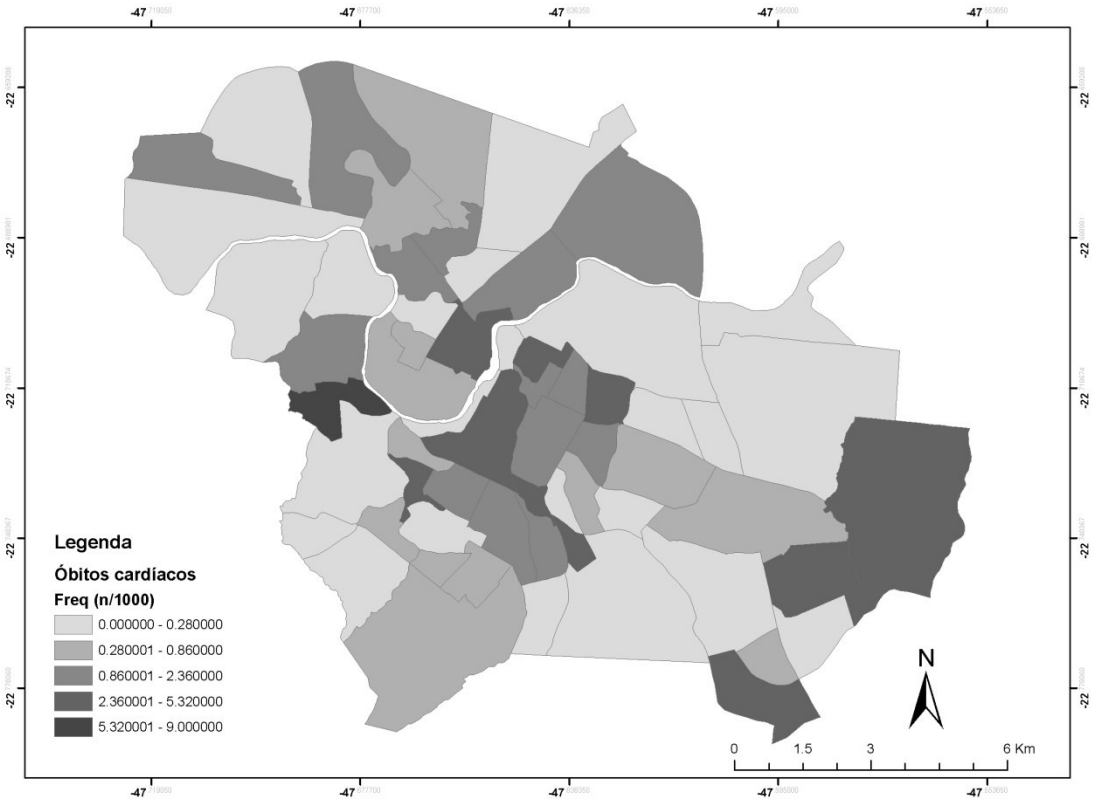
-47 719850
-47 677700
-47 636350
-47 595000
-47 553650
-22 595538
-22 595381
-22 595224
-22 595067
-22 594910
Legenda
Óbitos cardíacos
Freq (n/1000)
0.000000 - 0.280000
0.280001 - 0.860000
0.860001 - 2.360000
2.360001 - 5.320000
5.320001 - 9.000000
N
0
1.5
3
6 Km

Figure 6

CONSIDERAÇÕES FINAIS

Por meio do presente estudo, foi possível observar que as flutuações da concentração atmosférica de material particulado geram oscilações percentuais nas taxas de óbitos por doenças dos aparelhos circulatório e respiratório. Foi possível concluir também, que as concentrações de material particulado inalável sofrem influência direta da variável sazonal umidade relativa do ar e temperatura.

Embora esta pesquisa apresente limitações metodológicas quanto à analise espacial de dispersão do poluente estudado, é possível certificar que as queimadas detectadas na área rural do município, em sua maioria provenientes de lavouras de cana-de-açúcar, favorecem o aumento da concentração de material particulado para o município de Piracicaba, gerando impacto na distribuição espacial de mortalidade por doenças dos aparelhos circulatório e respiratório.

Observou-se houve uma melhora nos níveis da qualidade do ar do município de Piracicaba-SP quando comparado a estudos anteriores descritos na literatura.

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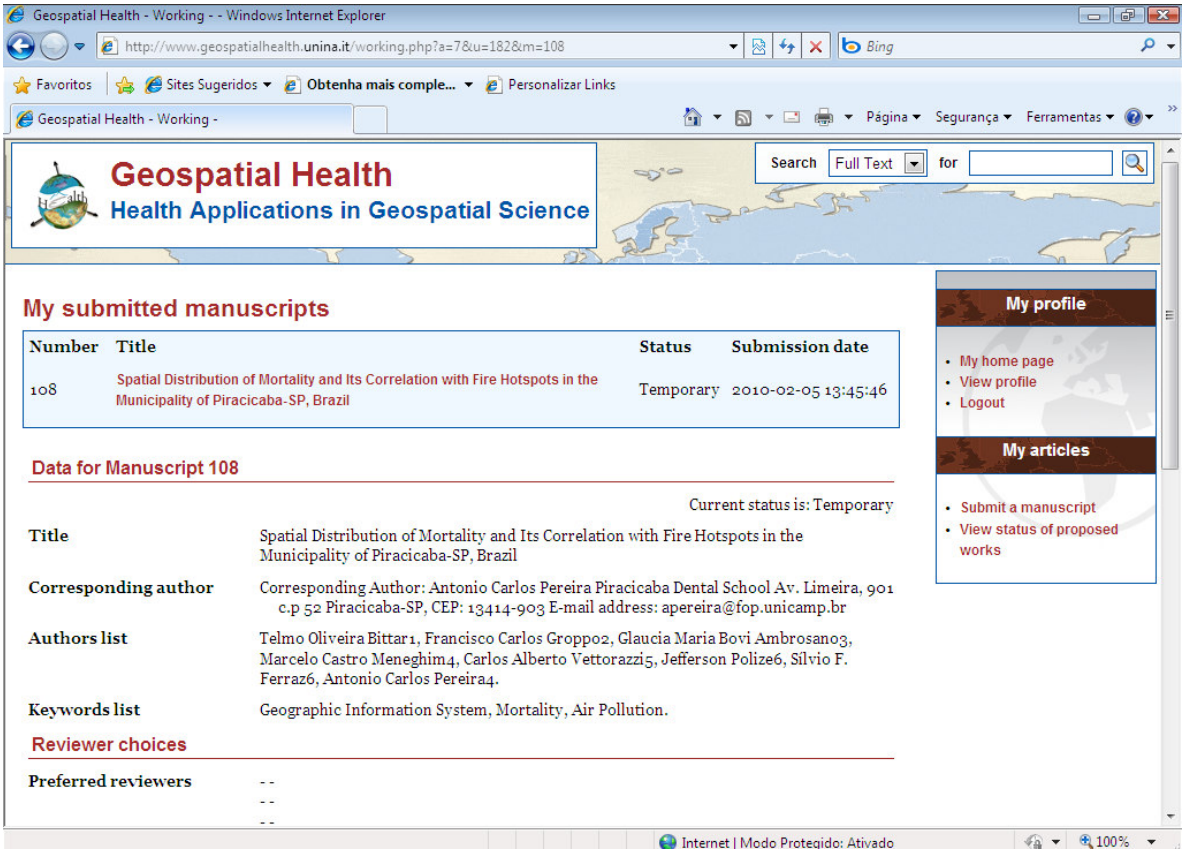
ANEXOS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Keywords list
Geographic Information System, Mortality, Air Pollution.
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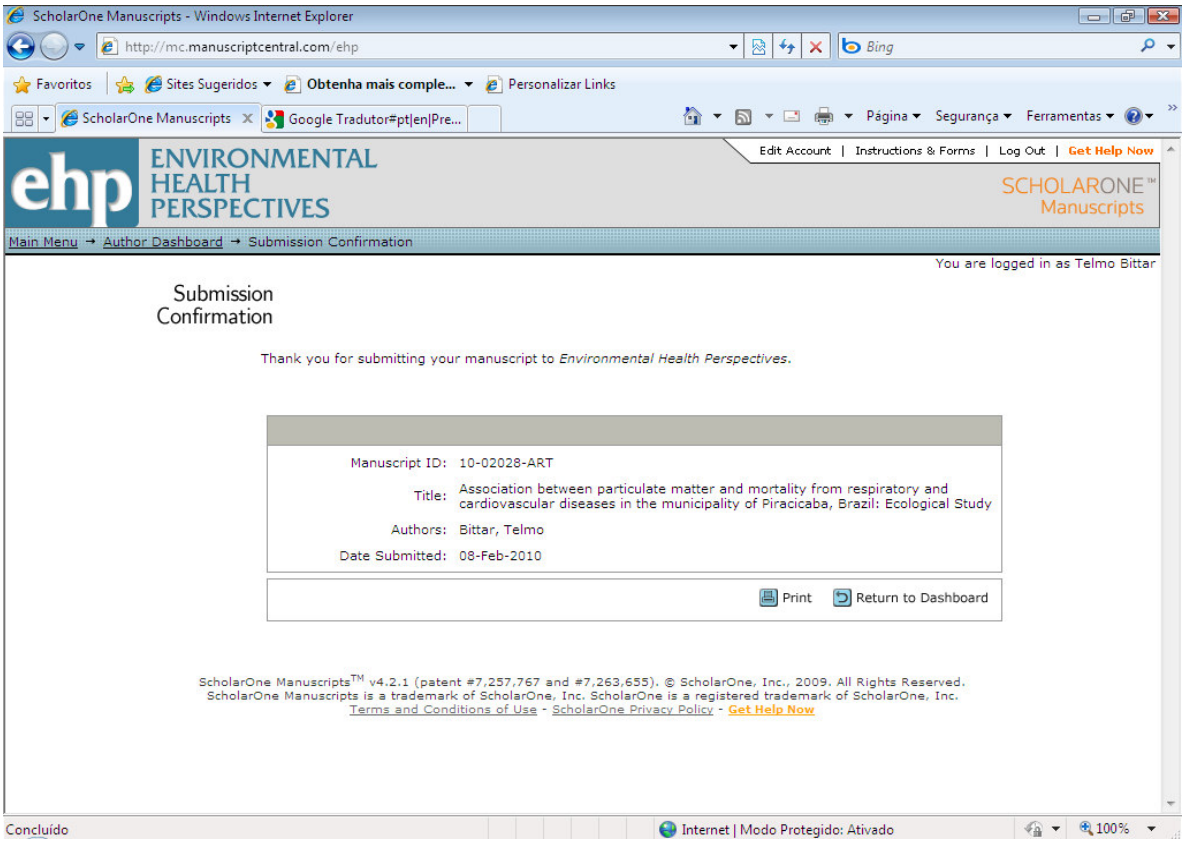
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FACULDADE DE ODONTOLOGIA DE PIRACICABA
UNIVERSIDADE ESTADUAL DE CAMPINAS

CERTIFICADO

O Comitê de Ética em Pesquisa da FOP-UNICAMP certifica que o projeto de pesquisa "**Estudo epidemiológico-experimental dos efeitos do material particulado proveniente da combustão da biomassa da palha da cana-de-açúcar sobre a saúde humana e animal**", protocolo nº **104/2007**, dos pesquisadores **TELMO OLIVEIRA BITTAR, ANTONIO CARLOS PEREIRA e FRANCISCO CARLOS GROPPO**, satisfaz as exigências do Conselho Nacional de Saúde – Ministério da Saúde para as pesquisas em seres humanos e foi aprovado por este comitê em 01/02/2008.

The Ethics Committee in Research of the School of Dentistry of Piracicaba - State University of Campinas, certify that the project "**Epidemiological and experimental study of particulate matter hazard from sugar cane biomass combustion over human and animal health**", register number **104/2007**, of **TELMO OLIVEIRA BITTAR, ANTONIO CARLOS PEREIRA and FRANCISCO CARLOS GROPPO**, comply with the recommendations of the National Health Council – Ministry of Health of Brazil for research in human subjects and therefore was approved by this committee at 01/02/2008.

Cínthia Machado Tabchoury
Profa. Cínthia Pereira Machado Tabchoury

Secretária
CEP/FOP/UNICAMP

Prof. Jacks Jorge Júnior

Coordenador
CEP/FOP/UNICAMP

Nota: O título do protocolo aparece como fornecido pelos pesquisadores, sem qualquer edição.
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