HEALTH VULNERABILITY OCCURRED DUE TO ATMOSPHERIC EMISSIONS: A CASE STUDY IN THE SANTA CATARINA STATE, BRAZIL

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1. INTRODUCTION

Air pollution is the greatest environmental risk to human health (UNEA, 2017). Air contamination accentuates the severity of respiratory infections (CHAUHAN; JOHNSTON, 2003). The risk of diseases associated with exposure to ambient air pollution is not uniform among populations (MAKRI; STILIANAKIS, 2008). They are defined as a function of air pollution events, vulnerability that depends on sensitivity (age, gender, race, among others) and the ability to cope of the population (socioeconomic status, education level, employment, among others), and exposure to the environment hazard (EEA, 2018; O'LENICK et al., 2019).

Therefore, ecological studies have been conducted to assess air pollution on population health at city and regional scales. Such perspective considers the evolutionary dynamics of social processes and aims to identify causes of disease incidence in populations and not the causes of disease in the individual, itself (BRASIL, 2007).

The state of Santa Catarina presents a context of economic and industrial development concerning to air quality. In 2017, the state had the highest number of vehicles per inhabitant in the country (CNT, 2018), as well as many industrial plants, being the 4th state with the highest number of industries in 2018 (CNI, 2020). In addition, between 2015 and 2016 the state showed an abrupt increase of 430% in emissions from fires. Which had reduced values in the year 2017, but still higher than the emissions of previous years (TEIXEIRA, 2020). Thus, besides the fact that the state of Santa Catarina has characteristics that are instigating for studies on air quality and health, it has few studies in the area (FONSECA; VASCONCELOS, 2011).

Consequently, the paper aims to present an ecological study which assess the association between atmospheric emissions, hospitalizations by respiratory diseases and the role of socioeconomic status in the State of Santa Catarina.

2. METHODS

2.1 Study Area

The state of Santa Catarina (SC) was the object of study of the work. We analyzed the state's 295 municipalities in 2017. Located in the south region of Brazil, the state has an area of 95,737.954 km² (IBGE, 2020b).

2.2 Data

The data obtained for vehicular and wildfire emissions for the year 2017 were used from the emissions inventory of the Air Quality and Control Laboratory (LCQAR, 2020a; LCQAR, 2020b). The pollutants were selected to include those that can cause harm to health as defined by the US Environmental Protection Agency (EPA, 2020d) and for SC state data availability. Thus, carbon monoxide (CO), nitrogen oxide (NOx) and particulate matter (PM) emissions were used. For the wildfire emissions, only Particulate Material ($PM_{2.5}$) was available in the particulates class. The emissions rates were used, and not pollutant concentrations, since there is not air quality monitoring in SC state

For socioeconomic index, Gross Domestic Product (GDP) per capita, Municipal Human Development Index (M-HDI) and the Gini coefficient were used. The GDP per capita was selected for the year 2017 (IBGE, 2020a). Both M-HDI and the Gini Coefficient were from the year 2010, according to the last census in the country. (UNDP; IPEA; FJP ,2013).

Respiratory admissions data were used to assess the effects of air pollution on human health. Data were extracted from Information Technology Department of the Brazilian Public Health Care System (DATASUS) for the year 2017 (BRASIL, 2020). The diseases were selected according to the International Classification of Diseases, Diseases of the Respiratory System (J00-J99). The hospitalizations were categorized into different ages: under 14 years old (children), between 15 and 59 years old (adults) and over 60 years old (elderly). These data were relativized, which means that each age group of individuals corresponding to the age group, to each 10 000 inhabitants per municipality.

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2.3 Statistical Analysis

We utilized an approach to assess the influence of variables on hospitalizations for respiratory diseases. Correlations were used using the Spearman and Pearson method. Both were used to verify the convergence of results. However, to discuss the paper results, only Spearman's method was considered, which the results will be presented in the figures, since it is a non-parametric approach and more appropriate to the distribution type of the variables used. Also, a Mann- Whitney Hypothesis teste was developed to verify the difference between medians among the municipality's groups of M-HDI range.

3. RESULTS

3.1 SANTA CATARINA

Figure 1 shows the Spearman correlation method with all municipalities in the state. The correlations between vehicular emissions of all pollutants and hospitalizations between children (CO (r = -0.232); NOx (r = -0.177); MP (r = -0.160)) and adults (CO (r = -0.157); NOx (r = -0.115)) were negative. For hospitalizations in the elderly, the correlation with the CO pollutant was negative (r = -0.135) and for the other pollutants they were not significant.

For emissions between wildfires and hospitalizations of children and adults, the correlations were not statistically significant. However, for the elderly age group (CO (r = 0.127); NOx (r = 0.129); MP (r = 0.123)) showed significance, with a positive value. Number of industries and hospitalizations in children (r= -0.226), adults (r= -0.128) and elderly (r= -0.127) presented negative correlations.

Regarding the analysis of socioeconomic variables and hospitalizations, for GDP per capita and hospitalizations, they were negative for adults (r= -0.150) and elderly (r= -0.122). The Gini Coefficient was not correlated with any age groups of hospital admissions and without significance. The M-HDI was negatively correlated with hospital admissions for all age populations: children (r =-0.190), adults (r =-0.201) and elderly (r =-0.207.

3.2 Correlação das variáveis de estudo por faixa de IDH

Figure 2 illustrates that, for all M-HDI levels, the variability in the number of hospitalizations predominates in the age groups of children and elderly. When comparing hospitalizations by age groups, for all age groups the percentiles increase as the M-HDI ranges decrease.

Figure 2 also presents the results of the hypothesis test. The results demonstrate that the groups with median differences are the adults and elderly groups, when the Very High and High M-HDI levels are compared, as well as the Very High and Medium M-HDI. When comparing the High and Medium M-HDI groups, the null hypothesis cannot be rejected in the age group of adults and elderly as well as it cannot be discarded for the age group of children in all M-HDI levels.

Analysis between hospital admissions and emissions for the Very High M-HDI city group revealed a negative correlation between vehicular emissions and respiratory disease admissions in adults (r= -0.645) and elderly (r= -0.664), the only correlations from such a source that proved to be significant (Figure 3).

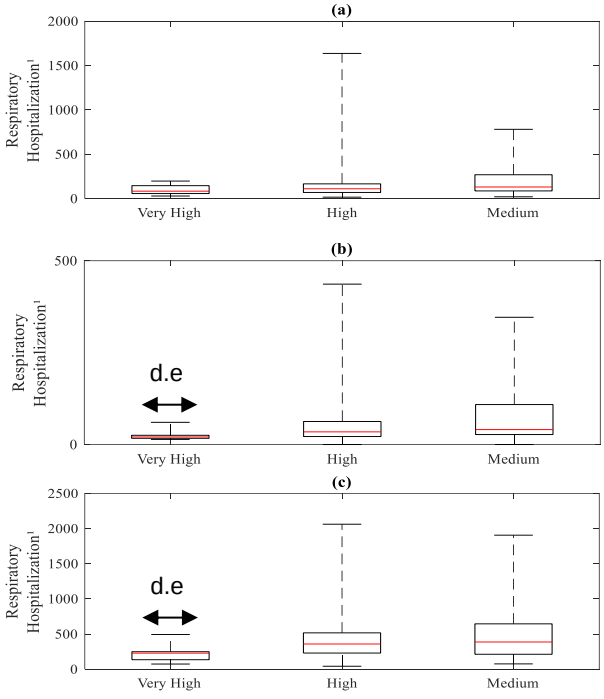

Figure 2: Comparison of respiratory hospitalizations by age group between M-HDI groups (a) children; (b) adults; (c) elderly. [1] Hospitalizations per 10,000 inhabitants. d = median difference of the High HDI-M; e = difference in the median of the Mean HDI-M

The correlations between wildfires and hospitalizations were not significant, despite having moderate correlation coefficients. However, when observing the correlation between hospitalizations in the elderly and burning emissions by the Pearson Method (CO (r=0.959); NOx (r = 0.963); $MP_{2.5}$ (r = 0.956) they were

positive. Almost half of the municipalities had zero emissions for this type of source.

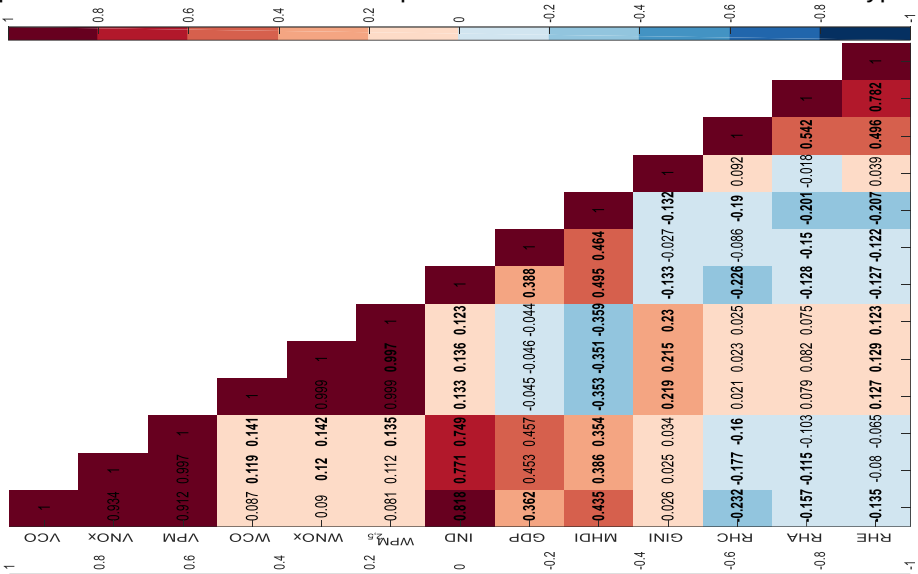

Figure 1: Variable's correlations with all municipalities in the SC state. N sample = 293 municipalities.

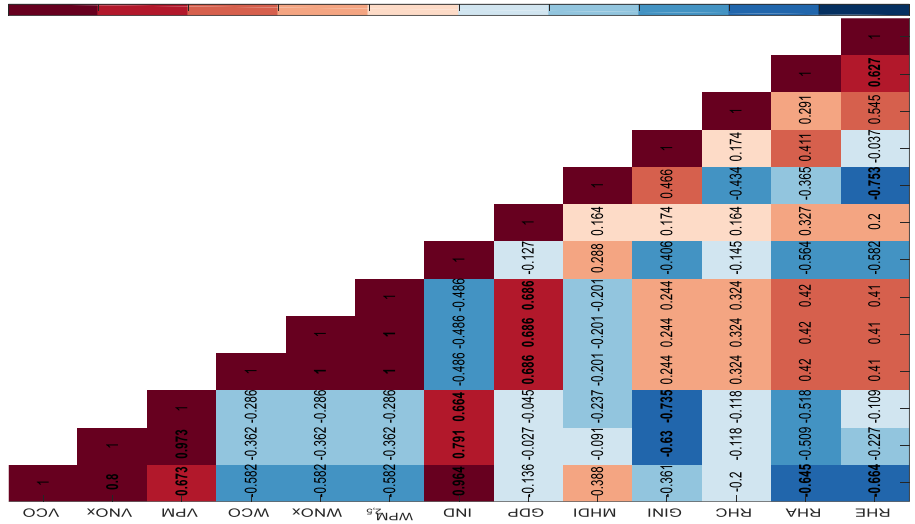

Figure 3: Variable's correlations in the municipalities for the Very High M-HDI level. N sample = 11 municipalities.

(Bold values represent statistical significance at the p<0.05 level. VCO- Carbon Monoxide by Vehicular Emissions; VNOx – Nitrogen Oxides by Vehicular Emissions; VMP- Particulate Matter by Vehicular Emissions; WCO- Carbon Monoxide by Wildfires Emissions; WNOx- Nitrogen Oxides by Wildfires Emissions; $WPM_{2.5}$ – Particulate Matter with diameter less than 2.5 micrometers by Wildfires Emissions; IND – Number of industries; M-HDI-Municipal Human Development Index; GINI – Gini Coefficient; IRC – Respiratory Hospitalizations in Children; IRA- Respiratory Hospitalizations in Adults; - IRI – Respiratory Hospitalizations in Elderly.

Correlations between hospitalizations and industry did not present any statistical relevance. Hospitalizations and GDP *per capita* were not significant also.

Just as for the Very High M- HDI level, when evaluating the correlations of the municipalities with the High M-HDI, vehicular emissions and hospital admissions were negatively correlated. However, statistical relevance is demonstrated for the age group of children and pollutants CO (r = -0.257), NOx (r = -0.192) and MP (r= -0.174). For the intermediate age group, CO (r= -0.199), NOx (r=-0.149). In the population over 60 years, the correlations between hospitalizations and the following pollutants from vehicular emissions were: CO (r = -0.188) and NOx (r = -0.133) (Figure 4).

Emissions from wildfires were not statistically significant when correlated with hospitalizations, even for the Gini Coefficient. The number of industries and hospitalizations in children (r =-0.225), adults (r =-0.170) and elderly (r=-0.186) were negative. As well as for the GDP per capita and hospitalizations in adults (r=-0.144) and elderly (r=-0.162).

When correlations were performed for the municipalities of Medium M-HDI, it was observed that vehicular emissions began to influence positively in hospitalizations for respiratory diseases, in a significant way, as presented in Figure 5. In this case, only adults and elderly people. The correlations between hospitalizations of adults and vehicular emissions: CO (r = 0.260), and NOx (r= 0.272). For the elderly: CO (r = 0.292), NOx (r = 0.321) and MP (r = 0.312).

For the case of correlations between the pollutants from wildfires and hospitalizations, they were not statistically significant, which can be

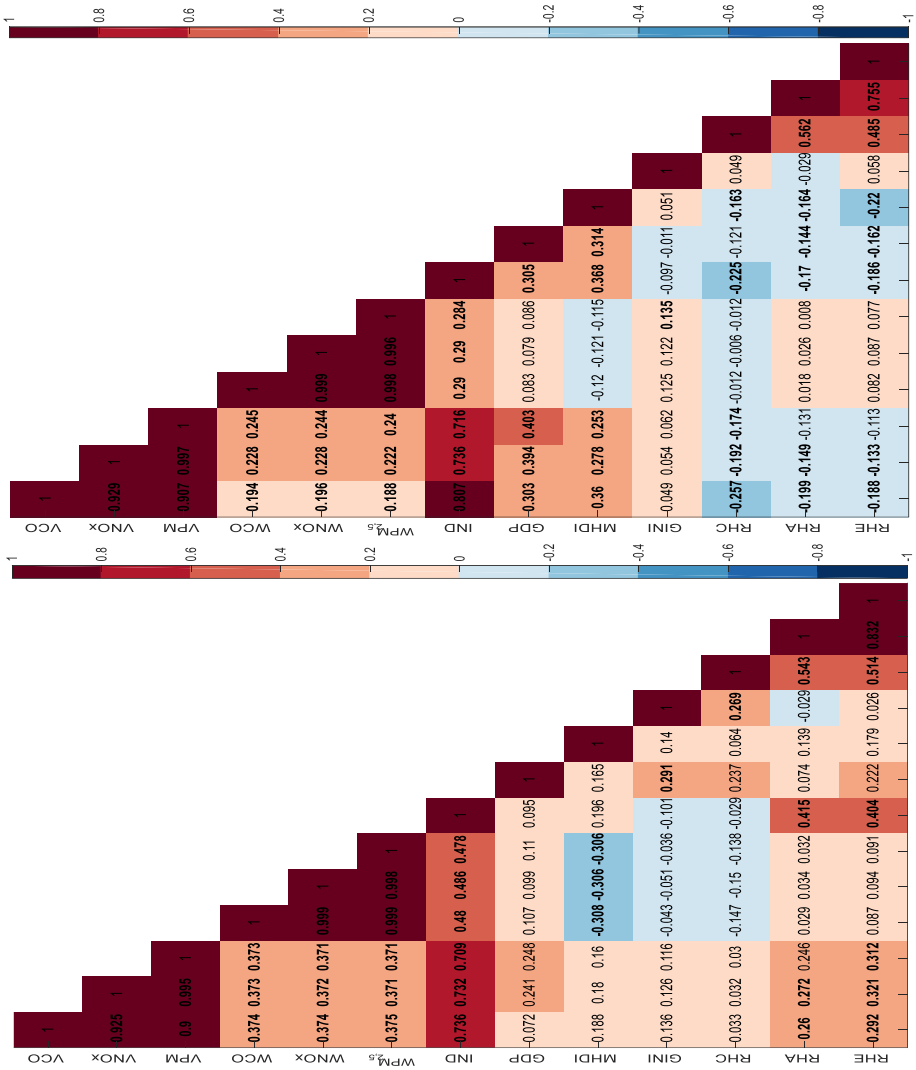

Figure 4: Variable's correlations in the municipalities for the High M-HDI level. N sample = 221 municipalities.

Figure 5: Variable's correlations in the municipalities for the Medium M-HDI level. N sample = 61 municipalities.

(Bold values represent statistical significance at the p<0.05 level. VCO- Carbon Monoxide by Vehicular Emissions; VNOx – Nitrogen Oxides by Vehicular Emissions; VMP- Particulate Matter by Vehicular Emissions; WCO- Carbon Monoxide by Wildfires Emissions; WNOx- Nitrogen Oxides by Wildfires Emissions; $WPM_{2.5}$ – Particulate Matter with diameter less than 2.5 micrometers by Wildfires Emissions; IND – Number of industries; M-HDI-Municipal Human Development Index; GINI – Gini Coefficient; IRC – Respiratory Hospitalizations in Children; IRA-Respiratory Hospitalizations in Adults; - IRI – Respiratory Hospitalizations in Elderly.

noticed for the GDP per capita variable as well. The industries showed a positive behavior in hospitalizations of adults (r= 0.415) and elderly (r= 0.404).

4. DISCUSSION

When fully evaluated, the state, the results show that vehicle emissions and the number of industries did not behave as a possible reason on the number of hospitalizations in respiratory diseases. That is, there were no positive correlations between vehicular sources, number of industries and hospitalizations. This fact can be justified since in most municipalities the emissions relate to the purchasing power of the population and have lower vulnerability in terms of ability to cope. In the same analysis, it was observed that GDP per capita and M-HDI correlated positively with vehicle emissions and number of industries. It is possible that air pollution from these sources does not affect these municipalities due to low vulnerability.

For the associations between socioeconomic variables and hospitalizations. The inverse behavior that these levels presented in relation to hospitalizations, shows that when populations are vulnerable in terms of M-HDI and GDP, they may suffer with higher risk respiratory diseases.

Analyzing the correlations of the municipalities for the Very High M-HDI groups, only for the age groups of older adults and adults, there were negative correlations between hospitalizations and vehicular emissions of the CO pollutant. For the M-HDI High level, as well as for the analysis performed in the whole state, the relationship between industries, vehicular emissions and hospitalizations showed a negative correlation behavior. Thus, the same justification used in the previous topic can be applied. This last group of M-HDI cited, both GDP per capita and HDI-M correlated positively to vehicle emissions.

The wildfires showed significant results only for the M-HDI Very High level, in the age group of

older adults and may have contributed to the number of hospitalizations in this group. For the High and Medium M-HDI range, the results were not so evident in this type of source.

For the Medium M-HDI correlations, it is observed that vehicular emissions and the number of industries have a positive influence on hospitalizations for respiratory diseases. These results can demonstrate that population when exposed to a greater vulnerable situation, might be suffering consequences related to air pollution.

Some studies conducted in Brazil, also have presented similar results, which the population suffers from the air pollution adverse health effects in vulnerability conditions (FONSECA; VASCONCELOS, 2011; IGNOTTI et al., 2010). It is important to report that, proximity to industrial complexes and development of diseases in the respiratory system are also reported (DE FREITAS et al., 2016; GOUVEIA et al., 2019), as well as for proximity to vehicular sources (REQUIA et al., 2016).

Both when fully municipalities evaluated analysis and in the one segregated by M-HDI groups (for the Very High and Medium HDI), the elderly population highlighted in the correlations between hospitalizations and emissions. Elderly population usually suffers at higher levels with air pollution due to its sensitivity and pre-disposition to respiratory diseases (EEA,2018; PINO-CORTÉS et al., 2020; QIU et al., 2018).

A divergent behavior between the two extremes M-HDI groups was still noticeable. For municipalities with M-HDI Very High, negative correlations were observed between hospitalizations and vehicular emissions, which may be explained because the populations of these municipalities are more adapted and thus less vulnerable. The possibility of a higher vehicle density is suggested, as characteristic of the high levels of GDP per capita. In this case they adapt better to these air pollution events. However, an adaptation limit is noticed when analyzing emissions from burning. It is known that the magnitude of the events caused by burning is much greater than that caused by vehicles. What can be inferred that for this type of pollution event the municipalities present a limit in terms of adaptation and thus are vulnerable to emissions from wildfires.

Thus, it is also possible to hypothesize that the opposite happens for populations from municipalities with Medium M-HDI level. Despite not showing significant correlations between emissions from wildfires and hospitalizations, the municipalities in this group are part of regions that stand out in terms of fire levels, such as the west and mountain. Meanwhile, when vehicular emissions are added, the populations of these municipalities have shown themselves the possibility of being vulnerable.

Further investigation is necessary to comprehend why fire emissions may affect municipalities with Very High M-HDI and vehicles may affect municipalities with Medium M-HDI. Some questions and hypotheses can be suggested, such as: it may be an indication that for both mentioned M-HDI ranges, the population responds with respiratory diseases when a stressor is added, in opposition to what naturally occurs in the municipalities (vehicular emissions for HDI-M Very High and burning emissions for the Medium HDI-M). In other words, can the combined effects of such emission sources potentiate adverse health effects regardless of the M-HDI level and its capacity to cope? Another suggestion would be to evaluate the vehicle fleet of both groups of M-HDI range. Would not the vehicular fleet of municipalities with higher M-HDI more recent and thus cause less emissions? As well, wouldn't the vehicular fleet of municipalities with Medium M-HDI be older and the number of emissions greater enough to cause adverse effects on health? These are questions that can lead to future research and guide the study area.

It is important to point out the limitations of the study. As there is no air quality monitoring around the state, to obtain concentrations of air pollutants, the present study used emission data and number of industries, which may have presented underestimated results, since it is not the ideal measurement unit for such objective. Understanding the problem is more difficult without such information. In addition, the method employed is simple, develop studies with more robust methods are needed. The researches of air pollution adverse health effects are complex and depend on several factors, which should be considered, such as meteorology for example.

5. CONCLUSION

The study performed a preliminary analysis under the influence of air pollution and socioeconomic indicators on respiratory admissions in the state of Santa Catarina, for the year 2017.

When fully evaluated, vehicle emissions and number of industries did not show to affect hospitalizations, so negative correlations were obtained in this case. Only wildfire emissions showed the possibility of impact in the age group

of adults and elderly. It can be concluded that such results are a consequence of the large part of the municipalities of the state having M-HDI Very High or High level and thus reflect on a good quality of life of the population.

When analyzing the municipalities in each M-HDI range, the evaluations expressed themselves more clearly. This is because there was a distinct behavior among the variables along the ranges of the index. It is concluded that air pollution, caused by vehicular emissions and numbers of industries, may have affected populations of municipalities that have the lowest index, for the year 2017.

Finally, this study raised hypotheses that may lead future research to understand how air pollution affects the health of the population of Santa Catarina state and comprehend in what conditions of vulnerability.

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