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ESTIMATES OF ATMOSPHERIC POLLUTION EFFECTS ON HUMAN HEALTH: METHODOLOGICAL AND THEORETICAL POSSIBILITIES FOR SÃO PAULO CITY

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ABSTRACT

The article aims to analyze the theoretical and methodological issues arising from the effects of atmospheric pollutants on life quality and on human health, in particular. The great flow of vehicles in São Paulo city generates not just an increase in the emission of pollutants (which has a negative effect on human health), but also traffic jams and slow traffic (causing stress in people) and an increase in automobile accidents. Mitigation of the effects of atmospheric pollution on human health could be obtained through the gradual introduction of a new fleet of clean vehicles in the city, but also by educating the population to use public transportation more.
In this article, the author briefly analyzes and describes the studies that have been carried out on the theme, as well as the methods used and the conclusions reached by them. Using a review of literature, the author indicates the next steps in her study on the atmospheric pollution effects on the health of the population in the city of São Paulo city and the metropolitan area.

Key words: Atmospheric Pollution, Human Health, Costs to Health

INTRODUCTION

We are living in a time that is unique in the history of humanity, with the rise of an environmental conscience. Until now man has believed that energy sources, or rather, natural resources were inexhaustible and could be consumed indiscriminately, without worrying about any possible scarcity problem. However, at the end of the XXth century it became evident to humanity that the current development model, because of its predatory nature and irrational use of natural resources, was exhausted. This model has also been questioned because of its perversity from the social point of view, because it is an extremely unfair system, where power is concentrated in the hands of few people; it even creates cultural alienation because of its harmful effects on nature and on humans themselves.

It is extremely important, therefore, that we begin proposing solutions for the various economic, social and environmental problems caused by the capitalist development model (GUIMARÃES, 1998). The transformation arising from these proposals will probably demand that man be capable of establishing a new relationship with nature, by substituting the current one - *dominator-dominated-* for a concern with maintaining or improving the quality of life of future generations, by seeking a more balanced and equitable approach (BARTHOLO JR., 2001).

One of the several problems caused by the capitalist development model is atmospheric pollution, a problem that is becoming increasingly more apparent in our major urban centers. At the beginning of the capitalist era, during the industrial revolution, a major part (if not all) of the atmospheric pollution came from industries, and this was classified as stationery sources[1]. However, the appearance of the internal combustion engine gave rise to a mobile source[2] that over the decades would become the object of desire of human beings: the automobile.

Today we have a situation where the biggest generators of atmospheric pollution in our major centers are the mobile sources traveling up and down our highways. In the case of the city of São Paulo it is known that 90% of the emission of pollutants comes from mobile sources. In this articles we shall use the term ‘mobile sources’ to indicate the means of transport that circulates in the city: light passenger and light commercial vehicles and heavy vehicles.

Some of the factors that give rise to these alarming indices are fundamental: the lack of encouragement to use public transport and its poor quality; a highly concentrated fleet that is also growing rapidly and continually (currently in São Paulo, there is one vehicle for every two inhabitants, [ARAÚJO, 2003]), and its preponderance as a means of locomotion. Society encourages the use of private individual transport in detriment to public transport. These factors end up contributing to the deterioration of the air quality in those places where the emissions originate, as well as in others that are more distant, because of the mobility of this fleet and the incidence of atmospheric currents. We also need to consider the low quality of fuel used in the vehicles and the large number of old vehicles in the total fleet that is circulating in the city.

[1] Stationery sources may be classified as occasional, or from a particular area. What differentiates one from the other is the fact that the first produces high magnitude emissions (in general complex industries are occasional stationery sources), while the second is a set of individual emissions. We can classify the pollution from house chimneys as low magnitude emissions and therefore we have to analyze it in a particular area.

[2] Sources that are in constant movement, circulating on highways (automobiles, trucks, buses and motorcycles) or off them (planes, trains and boats).

The overwhelming majority of old vehicles have no regular or suitable maintenance, which makes them pollute even more. We must also mention that a vehicle in a new fleet, where criteria are more strict as far as the emission of pollutants goes, and that has more advanced technology, if it is not regularly and properly serviced is going to pollute as much as a vehicle in an old fleet. It is, therefore, obvious that in addition to looking for more advanced technologies that lead to reduced emission of pollutant gases we also need to make the population aware of how necessary periodic preventive maintenance of their vehicles is.

The increase in the use of automobiles has two separate strands: the first has to do with the *status quo* that comes from owning and using private vehicles, which is seen as much in the upper and middle classes, as it is in the underprivileged members of the population.

On the other hand, we observe the widespread use of people carriers and 'public' taxis [carrying 4 or 5 passengers, but collected separately, like buses], stimulated by the inefficiency and poor quality of public transport. This uncontrolled increase in the use of automobiles has serious urban, economic and environmental consequences.

In the world today we have vehicles with two types of engine cycle: the Otto[3] cycle and the Diesel cycle. In this article we are only going to deal with pollutants emitted by vehicles powered by the Otto cycle, which are carbon monoxide, hydrocarbonates, nitrogen oxides and aldehydes. In particular, the vehicle fleet powered by gasoline, which corresponds to the majority of the vehicles circulating in São Paulo[4], also emits particulate material and sulfur oxides.

The long term solutions for the problem of the emission of pollutant gases from mobile sources has necessarily to involve improvements in the quality of the commercial fuels currently used and the search for alternative sources of energy. Because it is one of the main emission factors (along with engine technology) it is of utmost importance that research is carried out into new combustion technologies and devices that will control these emissions, as well as looking for clean fuels.

Making feasible the use of alternative fuels will make it possible to exchange traditional internal combustions engines for electric vehicles powered by combustible cells, also known as clean vehicles. Combustible cells can transform hydrogen into electrical power via a clean process, i.e. there is no burning of fuel during the power conversion process.

The introduction of vehicles that use hydrogen as a fuel will cause changes in the economic equation of the world's energy sector and could be the first step towards a more sustainable environment. The argument against adopting this technology lies not so much in the availability, or otherwise of the fuel, but in spreading the production technology for making this type of automobile and making it cheaper. A case study carried out by Esteves *et al* (2004) on the introduction of a new fleet of vehicles powered by combustible cells in São Paulo that the necessary amount of fuel is available (obtained from renewable sources; ethanol and hydraulic power), for producing the amount of hydrogen needed to keep this new fleet circulating and that fuel costs would be considerably cheaper than those it currently has using gasoline powered automobiles. What makes this project unfeasible is precisely the lack of publicity about the production process for hydrogen-powered vehicles, because it was seen in the study that the investment pay-back time[5] for

[3] The reaction of the Otto cycle engine starts with a spark, whicl the Diesel cycle happens by the fuel being compressed within the cylinders. Gasoline, alcohol and natural gas-powered vehicles use the Otto cycle.
[4] 91% of licensed vehicles (following the Ottto cycle) in São Paulo, in 2005, were automobiles. And nearly 62% of the automobile fleet uses gasoline as a fuel throughout the whole year.
[5] Approximately 32 years inthe case of the use of ethanol as a source of hydrogen, ad 46 in the case of the

vehicles with this differential (a vehicle with zero emissions) is far greater than the useful life of the vehicle itself [6] (ESTEVES *et al*, 2004).
The incentive for using mass transport, like buses, the subway and bicycles would be a good alternative to the problem. But there is a major hurdle to be overcome by part of the population with regard to the use of bicycles as a means of transport. In their vast majority the cycles-ways in our major urban centers are only being used for leisure purposes or physical exercise. Therefore, making the population aware of the possibility of using the bicycle as a basic means of alternative transport for covering short distances would also be a good alternative.

Despite the fact that the vehicles produced today fall within the norms established by the regulatory bodies[7], we need to develop vehicles that are less pollutant, given that the effects of the emission of the gases produced by these vehicles cause considerable damage to human health. Araújo (2003) showed the importance of adopting hew technologies, in this case the use in São Paulo of light vehicles powered by hydrogen fuel cells, in order to reduce the emission of pollutants in the city. The author puts forward two scenarios for introducing these vehicles: the first, where they would follow the same indices proposed for Los Angeles, California and the other, where the percentage of this fleet was closer to the Brazilian economic reality. From her work it is quite clear that there exists a lag between the adoption of measures and their effects, given that the effects of the technologies introduced in internal combustion vehicles (catalyzers – introduced between 1992 and 1996), and the mixture of alcohol with gasoline (introduced in 1980 according to CETESB), will still be felt in the year 2020.

A further step in reducing these harmful effects would therefore be the establishment of stricter gas emission norms, forcing the automobile industry to research into and use less pollutant technologies and make them cheaper, in order to be able to sell them in the market at competitive prices.
Based on the above the aim of this article is to deal with the theoretical issues of the effects that Sao Paulo's atmospheric pollution has on the population that lives there. The article will look more deeply into the methodologies available in literature in order to quantify the harmful effects of atmospheric pollution on health, by briefly presenting the theories and the background of studies that have been carried out by academics, using both the studies themselves and their results.

2. A brief overview of the methodologies used for evaluating the costs to health

Over recent years international health and social development specialists have been creating new ways of configuring the human misery that results from the increase in the number of cases of chronic disease and incapacity. These specialists have constructed new ways of measuring suffering from chronic disease (morbidity). The Daly method is an example of this type of approach.
Despite that fact that the effort for developing an objective indicator that helps when it comes to choosing how to allocate scarce resources between policies and programs is praiseworthy, the limits and dangers of configuring social suffering as an economic

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use of hydraulic energy.
[6] 20 years, on average.
[7] PROCONVE – Air Pollution Control Progrtam for Automotive Vehicles, created in 1980, with the purpose of determining pollutant gas emission limits.

indicator is questioned. A good alternative for avoiding economic indices becoming the only parameters authorized for constructing policies and programs would be to use these indices in association with social stories that touch on the human side of suffering (KLEINMAN, 1997).
The human health costs of environmental pollution can be calculated using the following approaches.

2.1. Defensive Spending Method

The main characteristic of this methodology is the fact that it measures only the direct income loss. An example illustrating this would be the salaries lost as a result of days absent from work or premature death and the additional spending incurred.

The biggest criticism is with regard to the possibility of estimating the expenditure in recovery, while forgetting the importance of calculating the amounts relative to choice and resistance. There are various ways of calculating this measure, all of them coming from classic economic theory. Among them we can mention the following approaches:

- **Human capital**: this uses the level of individual output to indicate the potential production that has been lost. It is based on the hypothesis that people demand the maximum salary they can obtain, given their capabilities. Salaries are only used as a measure of the loss of social production (MCCRONE, 1998).
- **Cost of illness**: this focuses on morbidity and its assumptions are also based on the theory of human capital. It treats morbidity costs as resulting from the medical expenses incurred in treating disease and the salary loss for the days when the individual is affected by it.
- **Preventive expenses**: this tries to infer the amount that people are prepared to pay so that health risks are reduced.
- **Salary differential**: this uses the differences existing between the salary rates for measuring the compensation that people need due to the differences that exist in their chances of getting sick or dying.

2.2. Contingent Valuation Method

The idea behind this method is to measure the compensation necessary so that a very high personal risk is accepted when compared with the salary rate for work where there are threats and those where there are not. For this analysis the method makes use of research (questionnaires), or the evaluation of market data, to determine how much individuals are prepared to pay to reduce the probability of their premature death by disease. This type of analysis has a very large bias, because depending on the person's situation and which stratum in society (social class) they come from their response patterns will be different. The questionnaire is the most transparent means of obtaining these preferences, but formulation of the questions plays a decisive role in this. Assessment of market data, on the other hand, shows us the real world, instead of a hypothetical situation (questionnaire) (ZWEIFEL, 1997).

The two approaches presented above are full of uncertainties and controversies because they are based on economic theory (which in itself is full of hypotheses and assumptions) and on the results (evidence) obtained from epidemiological studies.

2.3. An alternative approach – Daly method

The Daly method is a measure of the suffering produced by specific diseases, which combines the impact of premature deaths and the disabilities resulting from these diseases. The age at which the disease was contracted, the number of years life expectancy lost (the relative value of these years) and the years compromised because of the limitation are all taken into consideration (KLEINMAN, 1997). In other words, the basic characteristic of this alternative technique is its capacity to calculate onus indicators that are independent of the currency unit used in the country being studied, producing an indicator that is measured in years of life. Because of this it can be considered to be a standard indicator. This indicator comprises two components, one representing the years of life lost (YLL) and the other the years of life lived with a disability (YLD).

The years of life lost and the years of life lived with a disability are calculated in accordance with the mathematical equations set out below:

$$YLL_S = \frac{KCe^{ra}}{(r+\beta)^2}\left[e^{-(r+\beta)(L+a)}\left[-(r+\beta)(L+a)-1\right]-e^{-(r+\beta)a}\left[-(r+\beta)a-1\right]\right]+\frac{1-K}{r}\left(1-e^{Lr}\right) \quad (2.3)$$

where

r : discount rate

K : age-weighting factor

C : constant

a : age at death

L : standard life expectancy at age a

β : age-weighting parameter function

$$YLD_S = D\left\{\frac{KCe^{ra}}{(r+\beta)^2}\left[e^{-(r+\beta)(L+a)}\left[-(r+\beta)(L+a)-1\right]-e^{-(r+\beta)a}\left[-(r+\beta)a-1\right]\right]+\frac{1-K}{r}\left(1-e^{Lr}\right)\right\} \quad (2.4)$$

where

r : discount rate

K : age-weighting factor

C : constant

a : age at disability

L : duration of disability

β : age-weighting parameter function

D : disability weighting

3. Effects of atmospheric pollution on human health

Atmospheric pollution enormously degrades the quality of life of the population, causing a series of respiratory, cardiovascular and neoplasia diseases. We must point out that these three categories of morbidity comprise the main causes of death in the major urban centers (BARBOSA, 1990). In addition to this they also cause a reduction in the individual's immunological system, making him of her more susceptible to acute infections.

Those most affected by poor air quality are children, the elderly and people with respiratory problems (bronchitis, asthma and allergies). It is worth mentioning that 15% of the total population of the municipality of São Paulo is made up of children and the elderly, the group most susceptible to the harmful effects of pollution (MIRAGLIA, 2002). In children atmospheric pollution may result in significant school absences, a reduction in peak flow rates and an increase in the use of medication in those who suffer from asthma. In normal people, whether adults, children or the elderly, pollution causes changes in the immunological system (MARTINS, 2002).

Determining the main pollutant that is responsible for causing health problems is a complex task because of the difficulty in measuring all the pollutants in a city like São Paulo.

Among the various consequences of the deterioration in the health of the population living in cities whose characteristics are similar to those of São Paulo, is an increase in the cost of attending people in the public health services, given that the high levels of air pollution cause an increase in visits to emergency departments, basic health units and hospitals, both in the city as well as in the Greater Metropolitan Region. In other words medical consultations, hospital admissions and deaths increase, as do the consumption of medication and absences from school and work, and the practice of physical activities by the affected population is also restricted.

Various studies have been carried out over the years, both in Brazil as well as abroad, with the aim of showing the association that exists between variations in the volume of atmospheric pollutants and the increase in the incidence of respiratory and cardiovascular diseases. We shall deal with these studies in this item.

In his dissertation Martins (2002) carried out an investigation into the effects of atmospheric pollution on morbidity, caused by influenza and pneumonia in the elderly (people of 65 or more) in São Paulo. It is known that these services represent 6% of all the health services supplied to the elderly. In carrying out the study the following data were used:

- Daily number of cases of pneumonia and influenza dealt with by the emergency department of a hospital that is a point of reference in the city;
- Daily levels of CO, O_3, SO_2, NO_2, $PM_{10;}$
- Average temperature;
- Relative humidity of the air.

The data used included the period from May 1, 1996 until September 30, 1998, which makes it a time-series analysis study. The data listed were used to establish the relationships that exist between pneumonia and influenza and atmospheric pollution. The methodology used was Poisson's generalized additive regression model, where the daily number of reported cases of pneumonia and influenza depended on daily average pollution concentrations. Short and long duration seasonal adjustments were also carried out in the model. The descriptive statistics for all the variables mentioned and the Pearson correlation coefficient were calculated for pollution and the daily reported cases of influenza and pneumonia. Poisson's distribution was chosen because the number of cases dealt with represents an event that can be counted. The author also used a control variable; to obtain this she used the variables:

- Days of the week, adjusted for short duration seasonality;
- Number of days, adjusted for long duration seasonality;
- Minimum average temperature and relative air humidity, adjusted for meteorological variables,
- Number of non-respiratory problem cases attended in the elderly

▪ Daily automobile ban period [*Sao Paulo bans 20% of the automobiles from circulating in the city during the rush hours of every working day throughout the year, except for the school holiday periods – July and January*)

The relationship between these variables and the control variable was established using a generalized additive model with non-parametric smoothing functions, by removing long duration basic seasonal patterns. The model's parameters were chosen by minimizing Akaike's information. Moving averages for pollution were also tested to determine the lag structure that exists between the increase in pollution and the effect on the increase in the daily number of cases dealt with in hospitals. After the test period lags of two days were determined for O_3 and the average daily amount for all other pollutants.

After defining the model the effects of the increase in pollution on the number of reported cases was estimated. The author observed that all pollutants are interrelated, except CO and O_3. Particulate material (PM_{10}) has the greatest relationship with the other pollutants and the number of reported cases proved to have a fairly significant positive relationship with CO, SO_2 and PM_{10}. She also saw that an increase in the level of SO_2 to 15.05 $\mu g / m_3$ would cause an increase of the order of 14.5% in the daily reported number of cases of pneumonia and influenza in the elderly population. For O_3, an increase to 38.80 $\mu g / m_3$ would cause an increase of 8.07% in the reported number of cases.

In an article they wrote Cropper and Simon (1996) described some of the pitfalls that commonly appear when trying to estimate the monetary value of the benefit associated with a given reduction in pollution levels in developing countries. But they emphasis that, despite the countless pitfalls existing in this calculation process, it is extremely necessary.

The authors describe some of the measures for quantifying the impact of pollution, pointing out their possibilities and limitations. In the following paragraphs we shall describe the aspects dealt with by these authors.

According to Cropper and Simon (1996), epidemiological studies are considered the most appropriate way of measuring the impact of air pollution on mortality and morbidity rates, because they are capable of capturing both the acute as well as the chronic effects. They are cross-section studies of individuals monitored for at least 10 years, where the concentrations of atmospheric pollutants and other risk factors are measured. Studies like this are, however, unfeasible for the following reasons: the existence of a migratory flow that means that the number of people exposed to determined levels of pollution does not represent reality and the difficulty of controlling the confusion factors.

Time-series studies that relate daily variations in air pollution to variations in daily mortality rates avoid the problems mentioned above, but in the best cases they measure the effects of acute exposure to air pollution on the mortality rate. For this reason, they generally overestimate the years of life lost as a function of pollution.

As there is an absence of epidemiological studies in developing countries, they proposed using dose-response functions from other countries. These projections must, at the very least, be done for specific diseases. However, it appears not to make much sense to the study authors to extrapolate the effect of air pollution on total mortality rates obtained in the United States, if the causes of death differ enormously between there and developing countries.

Two methods are used to determine the value of the reduction in the risk of disease; compensatory salaries, where the value that compensates the salary differential in the work market is inferred, and contingent valuation, where people are questioned about how much they are prepared to pay to reduce their risk of dying. In developing countries premature death is calculated using the estimates of the value of a statistical life for the United States, and adjusted for the salary difference between the two countries, or by calculating lost earnings. Criticism of this methodology lies in the fact that the willingness to pay method provides a value of statistical life that exceeds that of the income lost as people become more risk-averse. The authors conclude the article by stating that while no advances are made towards supplying a value of statistical life for developing countries the alternative for valuing it will be to use the income lost as a lower limit and projections of the value of life from studies carried out in the United States as an upper limit for the value of the changes in life expectancy.

Romieu and Borja-Aburto (1997), in a theme that is relatively close to the previous one, although it has a different analytical focus, considered the generalization of the dose-response relationship and the importance of attempting to use it at the public health level.

When epidemiological generalizations are made some of the relevant matters to be considered in the relationship between particulate material and daily mortality are: identification of the agents responsible for the association and biological mechanism, the conditions of exposure to the agent and characterization of the susceptible groups. In the generalization process of this relationship it is necessary to analyze the similarities and the differences between North American and Latin American countries from three different angles:

- Mixture of atmospheric pollutants: particulate material is a mixture of different sub-classes of pollutants. Their size and chemical composition depend on atmospheric composition formation mechanisms and climatic variables. There are variations in this composition, both within, as well as between, major cities and between rural and urban areas. In São Paulo, for example, 41% of all particulate material is related to mobile sources, and 59% to industry. In contrast, in the western United Sates the main culprits are fugitive dust, motorized vehicles and wood smoke, while in the Eastern States stationery combustion and fugitive dust are the main sources;
- Exposure profiles: exposure estimation is probably one of the greatest deficiencies in studies of the relationship between particulate material and mortality and may be a serious problem when it comes to results generalization. In time-series analyses of mortality and particulate material, if we were able to assume day-to-day consistency with regard to individual patterns of activity and entire sources (houses and closed environments), we would therefore be able to adjust to a daily individual exposure. In this case we could have regressions with similar inclinations. Despite this, there is still an inappropriate classification and this may, therefore, modify the form of the dose-response relationship, particularly in moments when there is a low concentration of particulate material;
- Population characteristics: there are various differences between the North American and Latin American populations, among which we can mention their age structure, their morbidity pattern, the prevalence of disease co-factors, as well as access to and the amount of medical treatment available and the life style of the population, in general. Latin American populations tend to be younger, with high mortality rates. In Brazil, Chile and Mexico, the population of children under 5 is somewhere around 12%, while in the North America population it is only 7%; the base of the age pyramid tends to be narrower and the top wider.

For Romieu and Borja-Aburto (1997), in generalizing the results of North American dose-response function studies for Latin America, the greatest problem lies in extrapolating this function. Is it possible to assume similar inclinations in different locations, where the climatic and atmospheric conditions vary and consequently the air pollution mixture is different? According to Romieu and Borja-Aburto (1997), in order to be able to compare the dose-response relationships of particulate material between the United

States and Latin American countries we need a new generation of epidemiological studies. These studies must focus on the most susceptible individuals and include a better understanding of the events surrounding death, in order that an appropriate level of exposure for each individual can be determined. Assessment of exposure must focus on final particles and other pollutants and on climatic variables in order to have control over the model's interaction.

Romieu and Borja-Aburto (1997) conclude the article by stating that despite the countless uncertainties about the true dose-response relationship between particulate material and mortality we should not prevent control measures being implemented because of this, in particular because the true association is probably stronger than the one observed in epidemiological studies.

A study by Braga et al (2002) analyzed the processes that generate air pollution and its effects on health. In the article the authors describe the effects of various atmospheric pollutants. According to Braga et al, particulate material reaches the lower airways because it is an inhalable particle and not because of its chemical composition. It is a pollutant that is capable of transporting absorbed gases to the most distant areas in the airways, where the exchange of gases in the lungs occurs. The organism's defense mechanisms are sneezing, coughing and the mucociliar apparatus. During the study it was seen that 50% of the particulate material existing in houses comes from the outside environment, with the rest coming from smoking, cooking stoves and gas.

Ozone is a powerful oxidant and bactericide, capable of causing lesions in the cells and, just like particulate material, also in the most distant areas of the airways. Studies of exposure in human beings show there are three pulmonary responses, coughing, chest pains when breathing and a reduction in the forced ventilatory capacity.

Sulfur dioxide is most frequently associated with the total number of deaths and hospital admissions because of cardiovascular diseases (FREITAS, 2003) and is absorbed by the most distant regions in the lungs, when an increase in its ventilation occurs. It is eliminated by breathing out and in the urine. Acid aerosols, on the other hand, cause irritation in the respiratory tract.

The main source of carbon monoxide is urban transport, because automobiles emit this pollutant. It has been observed that healthy non-smokers living in areas with high indices of CO show an increase of up to 100% in the levels of carboxyhemoglobin when compared with healthy people and non-smokers who are not exposed to high indices of

CO. It is commonly associated with intoxication and its effects focus mainly on the heart (FREITAS, 2003).

Finally nitrogen oxides, when inhaled, reach the most outlying areas of the lungs due to their low solubility and their toxic effect is related to the fact that they are an oxidizing agent. The authors reviewed the epidemiological studies carried out in various urban centers and also did a cross-analysis between CETESB' air quality measures and the health data of São Paulo for more than 20 years and arrived at results that only go to reinforce the idea that we need air quality measures that are more restrictive than the current ones if we want to preserve human health. Some of their conclusions are listed below:

- Concentrations of pollutants in major urban centers cause acute and chronic problems in the respiratory tract, even when concentrations are below the standard air quality;
- Air pollution in São Paulo induces mutations in DNA, thus favoring the appearance of pulmonary tumors in humans and animals;
- In periods of thermal inversion, because of the accumulation of pollutants there is an increase in morbidity and mortality from respiratory and cardiovascular diseases, with a lag in the case of respiratory diseases;
- PM_{10} and $PM_{2,5}$ are the two pollutants most associated with damage to health and are frequently associated with cases of death from cardiovascular diseases.

In her Masters dissertation Miraglia (1997) presented the impact of the transport system on the health of the population in the municipality of São Paulo. In the dissertation she verified the association that exists between fuel consumption (ethanol, gasoline and diesel) and mortality rates in the elderly from respiratory diseases. The author used a statistical analysis model with data of mortality from respiratory and cardiovascular diseases, fuel consumption, the emission of pollutants (PM_{10}, CO,SO_2, O_3) and climatic variables. This statistical analysis model used linear regression techniques and the Poisson distribution, with the mortality, emission and climatic variables dependent. The analysis period comprises 1991 to 1994. Elderly people are considered to be individuals who are 65, or older.

The total number of daily deaths, the number of deaths from respiratory diseases, the number of deaths from cardiovascular diseases and the total number of deaths from non-respiratory diseases were used as mortality variables. The daily concentrations of PM_{10}, CO,SO_2 and O_3 were used as the pollutant variables. Data of the monthly consumption of gasoline, alcohol, diesel, fossil fuels, the total of all fuels and the ethanol consumption / fossil fuels ratio were used as consumption variables. The climatic variables used were temperature and the relative humidity of the air.

By analyzing the correlation between the fuel and pollutant data with data for mortality from cardiovascular diseases she showed the need to consider the existence of lag in the correlation; she used *lag* therefore, to represent it. Her presentation was done using moveable averages. Seasonality was also inserted into the model, due to the fact that in São Paulo pollutants do not disperse as well in the winter. It was inserted using *dummy* variables for months, the day of the week , temperature and humidity. The same methodology was used for cardiovascular diseases.

The model used proved the existence of an association between mortality from respiratory diseases and seasonal, climatic factors, pollution levels and fuel consumption. The same occurred with mortality data from cardiovascular diseases. PM_{10} was the pollutant most associated with this adverse effect in respiratory diseases, but not in cardiovascular diseases. With regard to fuel, the analysis showed no significant statistical association when related to mortality, but due to the fact that an association between fuel consumption and the emission of PM_{10} was observed Miraglia concluded that, despite the fact there is no direct association, there was, nevertheless, an indirect association. At the end of her dissertation the author proposes measures for mitigating these effects, such as prioritization of public transport instead of private individual transport and traffic restrictions, in association with the use of vehicle and alternative fuel technologies.

Continuing with her study, in her doctoral thesis (2002) Miraglia assessed the impact of air pollution on the population in São Paulo using a methodology that calculated the years lost and the years lived with disabilities. The methodology, known as the Daly (Disability Adjusted Life Years) Method was developed by the World Bank (Kleinman, 1997), and calculates a single health measure comprising two components. The first has to do with the years lost due to premature death (YLL) and the second has to do with the time lived under other than perfect health conditions (YLD). According to the author it has the advantage of being a standard indicator that does not suffer from the problems associated with currency and temporal basis conversions, and that produces a health measure expressed in terms of years of life. Her main purpose was to calculate the onus, but she also verified the effects that air pollution has on the life expectation of the population living in the city, in a universe made up of children and the elderly. In children she only analyzed morbidity and mortality from respiratory diseases, while in the elderly she analyzed morbidity and mortality from respiratory and cardiovascular diseases.

For her valuation Miraglia (2002) used the defensive expenditure and dose-response function to measure the number of events associated with pollution in each epidemiological study carried out in São Paulo and to estimate the costs in terms of health expenditure and the value of lives lost. For the calculation she used hospital admission unitary cost data and the value of life (VVE) was obtained from an analysis of various approaches. She concluded that the onus of the city's population, according to the Daly method, is 28,212 years of life lost and lived with a disability. It is worth pointing out that in her calculation she only took into consideration the two most susceptible groups, children and the elderly. In children the morbidity and mortality cost from the effect of atmospheric pollution is 12,266 years of life and in the elderly it is 15,946. While in children only 39% of the value represents premature death, in the elderly the variable is responsible for 60% of the calculated years of life, which emphasizes that the value obtained is underestimated because it does not include all the adverse effects on health, nor does it include all age bands.

In his article, Azevedo et al (1999) analyzed the importance and the correlation that exists between climatic variables and atmospheric pollutants and the incidence of respiratory diseases in children who, between January and July 1998, were attended in the Emergency Pediatric Department of the Professor Edmundo Vasconcelos Hospital in Sâo Paulo.

For Azevedo et al (1999) a substance is considered to be a pollutant when it can make the air improper to breathe, harmful and prejudicial to people's health and is an inconvenience for public health. In the article a retrospective study was carried out on the number of children, maximum age 5, who were assessed in the Department between January and July, 1998. These months were particularly chosen because it is known that between January and April pollutants are more easily dispersed than in May and June. They used data of daily morbidity rates from respiratory diseases that were grouped month by month, the daily amounts of PM, NO_2, CO, SO_2, the maximum and minimum daily temperature and the maximum and minimum humidity of the air.

The authors chose to use univariate statistical methods for analyzing the data. They therefore used the Pearson correlation coefficient, simple linear regression and multiple linear regression. Analysis of the correlation coefficients and the simple linear regression showed that the variable month had a high correlation with the number of people attended in hospital. This is evidence of the existence of seasonality. Carbon monoxide and the humidity variables presented no significant correlation, while sulfur dioxide and particulate material showed significant correlations. The temperature variables provided evidence of an inverse correlation with the number of those attended, i.e. the higher the temperature the fewer the number of people attended in hospitals.

The article's next step was to carry out multiple linear regression analysis, because it allows for confirmation of the presence of variables that are associated among themselves, in addition to explaining the variation in the numbers of those attended on a daily basis. In this alternative modeling the month variable was not to be included because it was supposed that it was perhaps creating a confusion effect. The result of this second analysis showed that minimum temperature was the most important variable, with an inverse correlation, and that particulate material had a direct correlation. In the first model the variable month was the most important.

The article's results showed a notable increase in the number of children attended during May and June, which in Brazil are the winter months, when pollutants are dispersed with difficulty. When the seasonal variation was withdrawn from the model the multiple linear regression showed that the increase in the number of children being attended because of respiratory diseases occurred because of falls in temperature and the amount of particulate material. The results reinforce the hypothesis that temperature and the levels of particulate material have a direct influence on the incidence of respiratory diseases in children.

In her masters dissertation Azuaga (2000) presented an analysis of the light vehicle fleet, using an environmental damage index (EDI) to do so. The author developed a calculation methodology that measures the environmental damage index (EDI) based on an analysis of the life cycle. Instead of dealing with the whole vehicle production cycle Azuaga (2000) chose to deal only with the vehicle's use phase, because she believes that within the whole process this is the phase when the most significant part of the damage occurs. In her dissertation she also analyzed the avoided cost of environmental and health damage, by calculating how much could be saved with, among other things, a reduction in health expenditure, the maintenance of buildings and losses in agriculture. The dissertation estimates the size of the light vehicle fleet for the year 1998, the average emission of pollutants (CO, NO_X, HC) and the fleet's average kilometrage. It also deals with aspects related to environmental impact, human health and the transfer of damage costs. For this analysis Azuaga (2000) looked at four scenarios that are briefly described below:

- Maintaining the 1998 fleet, including its composition;
- Maintaining the 1998 fleet, but changing its composition. In this scenario 100% of the fleet would be made up of more energetically efficient vehicles, with lower emission factors;
- Fleet projected to 2020, in line with probable tendencies;
- Fleet projected to 2020, in line with an optimistic hypothesis, where the vehicles would be using more efficient technologies.

Azuaga (2000) concluded that if the current tendencies continued, in the year 2020 we shall have an increase of approximately 70% in environmental and health damage, and if technological improvements are not introduced into the market we shall have the same costs as currently. With regard to fuel costs in the scenario where the current trends are maintained we would have an increase in costs of around 100%. When compared to the scenario where new technologies are introduced and the tendencies are maintained, we have a reduction of 44% in costs. The study showed how very important integrated policy planning is, the objective of which is an improvement in the quality of life of Brazilians, through the control of the private transport sector, thereby reducing risks to the environment and to human health.

In the seminar, '*Transport and air quality when constructing a healthy city*', Correia (2001) talked about the problems and difficulties he encountered in the research and experiments he carried out in the Atmospheric Pollution Experimental Laboratory of the University of São Paulo's Medical School.

According to Correia (2001) the major difficulty faced in determining the effects of atmospheric pollution on health comes from the fact that there are covariables that are difficult to control. Among them we can mention both active and passive smoking, working environments and population diversity. In an attempt to get around the problem the Pollution Laboratory carried out a series of experiments in which rats and guinea pigs were exposed for prolonged periods (3 months to 1 year) to the atmosphere in the center of São Paulo and compared, in the second stage, with other rats that had been kept in the rural zone of Atibaia (because it has climatic conditions that are similar to those in the city of São Paulo) for the same period of time. The results showed that the rats that stayed in São Paulo developed hyper-reactive bronchitis, in addition to presenting a dysfunction in the mucociliar apparatus that made them more susceptible to respiratory diseases.

The use of statistical tools, like time-series analysis, opened the doors to a more detailed investigation into the effects of atmospheric pollution in man. Using this tool significant effects were observed between the variable and child mortality, which was dominated by respiratory diseases. Another important aspect observed was that there is no level of safety for pollutants - a safe pollution level - below which there are no effects on human beings; air quality indices preserve health up to a certain extent, but only in the average population.

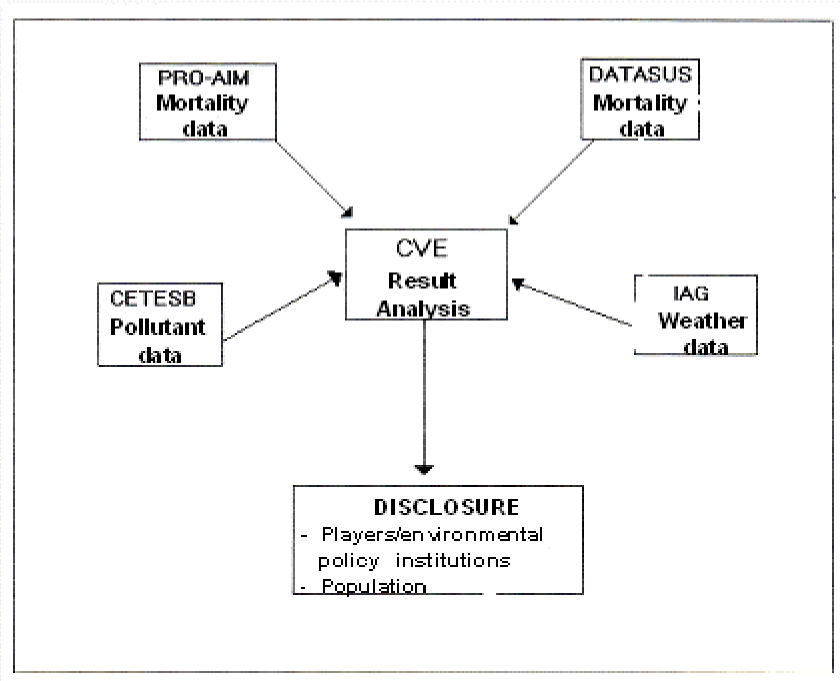
A criticism that is made of these types of study is that there is a very narrow window of time relative to the time between the pollution variation and the increase in mortality, and that therefore, it might be capturing only a 'collection' of susceptible individuals.

In addition to the studies we have mentioned a study was also carried out where the existence, or not, of negative impacts on pregnant women caused by atmospheric pollution was analyzed. The results indicated that an increase in intra-uterine mortality is to a certain extent associated with increases in the concentration of nitrogen dioxide and carbon monoxide.

Purely for comparison purposes Correia (2001) mentioned the study carried out in 6 North American cities over a period of 16 years. In the study 1000 people were monitored with the aim of studying their relative risk of dying early because they lived in a polluted city. The main conclusion of the study was that the more polluted the city the greater the risk of having your life cut short. According to the author the results obtained by the laboratory are not unique and just go to confirm the results obtained by other research groups.

The study carried out by Freitas *et al* (2003) proposes the use of a system that couples the information produced by the environmental control bodies to health information, using analysis techniques that explain the relationship between pollutants and morbi-mortality. The aim of creating this system is to supply elements and support the determination of national public policies, thus optimizing air quality vigilance and observation of sanitary indicator tendencies. The system proposed by Freitas et al (2003) would function in the way described in Figure 1.

Figure 1: System for analyzing morbi-mortality.



Source: Freitas et al (2003).

The establishment of vigilance would be done according to the analysis of daily data in hospital admissions and deaths per morbid occurrences of the age groups at greatest risk (death: over 65;admissions for respiratory disease in children: under 15), from 1993 to 1997, in the municipality of São Paulo. The Poisson distribution was used from additive and linear generalized models. As both the models presented very similar results it was decided to use the generalized linear model, as described below:

$$\ln\lambda_t = \alpha + \sum \beta_i \chi_{it}$$

(4.1)

where

$\ln\lambda_t$: natural logarithm of the dependent variable

χ_{it}: independent variables

α e β : hyper-parameters of the model

Before constructing the final version of the model temporal variations were also modeled (secular trend, seasonal and daily variations), control of variations caused by deficiencies in the health system itself (strikes, access difficulties) and temperature and humidity modeling, supposing that they bear some relationship to morbid occurrences. The model was adjusted by analyzing the total waste and temperature and the partial residual auto-correlationship. After this analysis the model was constructed as described in the following table.

Table 1: Description of the Model.

Dependent variables	Independent variables
Hospital admissions because of respiratory diseases in children; Death in the elderly;	Particulate Material (seven day moving averages); Minimum daytime temperature; Minimum daytime humidity; Months of the year; Days of the week; Study years; Admissions for non-respiratory diseases; Quartiles of temperature;

Source: prepared by authors from Freitas et al (2003).

Estimates of the relative risk (RR) and the 95% confidence interval (CI) were calculated and with these values the estimate of the growth and the statistical extrapolation of the population studied were obtained. The mathematical formulae necessary for obtaining the results are presented below.

$$RR = e^{\beta}$$

(4.2)

with β calculated for $1\,\mu g/m^3$;

$$IC = e^{[\beta \pm 1,96 ep(\beta)]}$$

(4.3)w

where ep is the standard error of the model;

$$RA = e\left(^{\beta poluente * poluente} - 1\right) * 100$$

(4.4)

where pollutant is the monthly average of the pollutant;

$$NA = \frac{(RR - 1) * N}{RR}$$

(4.5)

where N is the average number of hospital admissions for respiratory diseases, or deaths, in the elderly.

Freitas (2003) concluded that particulate material proved to be a good indicator of the short term effects on health. During the study it was detected that approximately 10% of hospital admissions for respiratory diseases in children and 9% of deaths in the elderly have a very close relationship with atmospheric concentrations of particulate material.

4. Final considerations

These are only some of the many studies that have tried to analyze the effects of atmospheric pollution on human health. Besides the studies presented there are also a whole range of studies that use plants in their analysis of the effects of air pollution. These plants are considered to be bio-indicators. Nevertheless, we have chosen not to present them in this review because they do not fit within the scope of the author's doctoral work. It is important to emphasis that these studies are only a small part of the studies carried out on this topic and that a more in-depth and on-going analysis of the same is the first step to choosing the best path to follow. For the author the path to be followed for establishing the relationship between morbidity from respiratory diseases in children and the elderly in the city and Metropolitan Region of São Paulo will be the use of the Generalized Additive Model, following a Poisson distribution. Results of this analysis will be included in a future article.

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