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Historical overview of air pollution in Sao Paulo metropolitan area, Brazil: influence of mobile sources and related health effects

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Abstract

Sao Paulo, Brazil, a metropolitan region with 39 municipalities and a continuous urban sprawl of 1,051 square kilometers and 16.5 million inhabitants, is responsible for 18% of the country's GNP and six million jobs. Over 40,000 industries and 5.7 million vehicles are registered there (25% of Brazilian car fleet). Three million cars circulate daily and 1 million drive in every day (350,000 trucks). The average car speed is around 17 km/h. These facts cause prohibition of circulation of 20% of passenger cars daily.

During the 1970's air quality had an important influence from industrial sources. Nowadays emissions come mainly from vehicles (97.7% of CO; 96.2% of NOx; 97.8% of HC; 69.3% of SOx and 49.3% of particles). Light-duty vehicles are powered by gasohol (mixture of 78% gasoline and 22% ethanol) and by ethanol. Heavy-duty vehicles are diesel-oil fueled.

Strong pollution control for stationary sources and a program of emissions reduction for new vehicles were put in practice, but only sulfur dioxide concentrations were greatly reduced. Levels of other pollutants are still above air quality standards during part of the year, in some neighborhoods. Higher number of cars neutralized efforts.

Surveys conducted in the 1970's and 1980's showed correlation between air pollution levels and respiratory symptoms. Comparison done in 1998 showed that symptoms decreased in neighborhood where pollution control programs were successful, but increased where only sulfur dioxide levels were reduced and other pollutants increased. Nowadays, there is concern in relation to ozone's health effects for its concentrations surpass standards.

This paper discusses air pollution in Sao Paulo, control programs, their efficacy, vehicle emissions and effects on health.

1 Introduction

Effects on human health and increase in mortality levels caused by air pollution have been described extensively in the international literature.

Metropolitan regions are important in terms of public health because large numbers of people live in them and air pollution levels usually are higher than in other areas because of concentration of human and economic activities.

Environmental control plans must include objectives and targets for the improvement of environmental conditions and also for a better quality of life for the population. The programs need to address indicators of improvement of air conditions and take in consideration cost-benefits. An important role of the University and other research institutions is the development of studies and researches to subsidy the development and to measure the efficacy of such programs.

2 Air Pollution in Sao Paulo

In Sao Paulo studies and researches on air pollution started in the late 1960's and became more intensive in the 1990's, specially in relation to health effects.

Sao Paulo is the third largest city in the World in terms of population. Its metropolitan region comprises 39 municipalities in a continuous urban sprawl of 1,051 square kilometers and 16.5 million inhabitants, more concentrated in seven municipalities where population density is very high. The municipality of Sao Paulo, with 10 million people, is in the center of this dynamic urban area. The region is responsible for 18% of the country's GNP and six million jobs. Over 40,000 industries and 5.7 million vehicles are registered there (25% of Brazilian car fleet). Three million cars circulate daily and 1 million drive in every day (350,000 trucks). Average car speed is around 17 km/h. These facts caused prohibition of circulation of 20% of passenger cars daily, from 1996 to 1998, in selected cities, to prevent air pollution episodes. Nowadays, circulation prohibition is restricted to rush hours and to the expanded downtown area of the city of Sao Paulo, mainly to minimize bad traffic conditions.

Industrial activities dominated the economy of the region until the 1980's. In fact, this is where industrialization most prospered in Brazil, influenced mainly the installation of car industries at the end of the 1950's. The 40,000 plants located in the region are of a very diverse nature in terms of size and type. A large number of them are of small and medium size. Almost all sectors are present: automobile, chemical, steel, textile, food, etc.

An usual practice in the 1960's and in the 1970's was the installation of industrial plants close to residential areas, so neighborhood complaints were very frequent and, in several cases, there were situations of health risks. Additional health risks are due to the increasing number of vehicles in the streets, most of them with a single person. Alcohol fueled cars which represented 50% of the fleet in 1989, nowadays represent only 20%.

The process of industrialization and land occupation, together with meteorological conditions unfavorable to the dispersion of pollutants (frequent low altitude thermal inversions during wintertime and strong solar radiation during other seasons) and a topography formed by floodplain surrounded by mountains in the north and northwest, receiving predominant winds from the ocean at southeast (approximately 60 kilometers away) result in conditions that favor deterioration of air quality.

3 Air Pollution Control Programs

In the more industrialized neighborhoods of Sao Paulo, occupied by the car industry (VW, GM, Ford and Mercedes Benz), air pollution control programs started in the 1970's, based on population complaints and involved restrictions to the installation of industrial plants and in treatment of emissions. This helped to change the industrial profile of the region as it motivated the transfer of many industrial plants to the inland areas of the State of Sao Paulo or to other Brazilian states. Also new and lower standards of maximum sulfur levels in fuel oil and the substitution of fuel oil by hydroelectric power or by natural gas in industries had positive effects. These actions caused reductions of air emissions from industry but, at the same time, emissions from mobile sources increased as a result of higher numbers of vehicles and very little control of their emissions. Nowadays, commercial and service activities, in the region as a whole, are increasing at a faster rate than industrial ones. In the municipality of Sao Paulo the Tertiary sector is already responsible for the majority of jobs.

The existing legislation can be considered strong for industrial emissions and for new vehicles. The legislation on new vehicles was enacted in 1986 by the act 18 of the Brazilian Council on Environment (CONAMA) that set a schedule for the reduction of the emissions from new vehicles. The most stringent emission standards were set for the year 1997. For light duty vehicles, they are similar to the ones of developed countries (2 g/km for CO; 0.3 g/km for HC and 0.6 g/km for NOx). The reduction schedule for heavy duty vehicles emissions is less stringent than for light duty vehicles and is based on European regulations. The most stringent regulation will be enforced in January 2002 (4 g/kwh for CO; 1.1 g/kwh for HC; 7.0 g/kwh for NOx and 0.15 g/kwh for particles).

Air quality management in Sao Paulo started based upon air quality standards and in emission standards for stationary sources set in 1976. The air quality standards were set initially for 4 major pollutants (Suspended Particles, CO, SO2 and Photochemical Oxidants) with levels similar to primary standards of the US Environmental Protection Agency (USEPA). In 1990 air quality standards were revised and the new ones incorporated primary standards, for the protection of public health, and secondary standards for the protection of the environment and for human wellbeing in relation to Suspended Particles, Inhalable Particles (PM10), Smoke, SO_2, CO, NO_2 and Ozone. Present day standards are shown in Table 1.

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Table 1: Brazilian national air quality standards (μg/m3)

Pollutant	Primary Standard	Secondary Standard
Carbon Monoxide	40,000 (1-hour average) 10,000 (8-hours average)	Same as primary
Nitrogen Dioxide	320 1 hour average 100 (annual mean)	190 (1 hour average) 100 (annual mean)
Sulfur Dioxide	365 (24 hours average) 80 (annual mean)	100 (24 hours average) 40 (annual mean)
Ozone	160 (1 hour average)	Same as primary
Total Suspended Particles	240 (24 hours average) 80 (annual mean)	150 (24 hours average) 60 (annual mean)
Inhalable Particles (PM10)	150 (24 hours average) 50 (annual mean)	Same as primary
Smoke	150 (24 hours average) 60 (annual mean)	100 (24 hours average) 40 (annual mean)

Source: Brasil, Resolução CONAMA, 1990 [1]

4 Effects of control programs on Air Quality in the Region

During the 1970's air quality was mostly influenced by industrial sources. Regulatory mechanisms, improved technology, and the location of many heavy industries in other parts of the State and of the country have reduced fixed sources of air pollution to the point where vehicles are the determinant factor in air quality. Tables 2 and 3 show the inventory of emissions from fixed and mobile sources in Sao Paulo in 1999 and in 1977, when the air pollution control program started, respectively.

From these Tables it can be noted that pollutants from industrial sources had a great reduction and the participation of mobile sources has increased in the 22 years period. It can also be noted that absolute emissions of SOx and Particles had a great reduction (SOx 82.6% and Particles 59.5%), emissions of CO had a very small reduction (1.3%) and HC and NOx had significant increases in emissions (HC 45.4% and NOx 200%)

Table 2: Emissions in Sao Paulo metropolitan area, 1999 (1 000 metric tons)

Source type	CO	HC	NOx	SOx	Particles
Gasohol vehicles	796.4	196,2	46.2	11.5	4.6
Alcohol vehicles	215.6	42,7	14.6	-	-
Diesel vehicles	401.2	65.3	293.0	25.5	18.3
Taxi	60.8	6.2	3.5	0.8	0.4
Motorcycles	178.4	36,3	1.3	0.8	0.4
Other transport and related sources	-	15.0	-	-	6.9
Industrial sources	38.6	12.0	14.0	17.1	31.6
Total	1,691	373.7	372.6	55.7	62.3
% from mobile sources	97.7	97.8	96.2	69.3	49.3

Source: CETESB, 2000 [2]

Table 3: Emissions in Sao Paulo metropolitan area, 1977 (1 000 metric tons)

Source type	CO	HC	NOx	SOx	Particles
Gasohol vehicles	1,557	183.8	51.7	11.2	8.5
Diesel vehicles	58.3	9.8	40.4	20.9	3.5
Other sources	42.9	23.9	2.6	.32	30.8
Industrial sources	56.6	39.3	29.1	288.6	111.2
Total	1,715	257	124	321	154
% from mobile sources	94.2	75.3	74.3	10.0	7.8

Source: CETESB apud Assuncao and Galvao Filho, 1999 [3]

Since 1981 CETESB, the Sao Paulo State Pollution Control Agency, runs a network of 22 automatic monitoring stations within the Metropolitan Area of Sao Paulo that measure Carbon Monoxide, Suspended and Inhalable Particles, Sulfur Dioxide, Nitrogen Oxides, Hydrocarbons, Ozone and some meteorological data. Before 1981 a limited number of non-automatic stations (manual network) were already running measuring TSP Smoke and SO_2 and one *automatic monitor in downtown area* of Sao Paulo measured CO. Their parameters can be compared to the National Standards of air quality in order do define control strategies.

Historical data on air quality in the region have shown that there was a great improvement in the air quality for SO_2, the annual mean in 1982 was close to 80μg/m^3 and in 1999 the average annual concentration was below 20 μg/m^3, in contrast with the annual primary air quality standard (80 μg/m^3). In relation to small particles (PM10) there was also an improvement in the air quality, but not so significant as that of SO_2. In 1982 the average annual concentration of PM10 in the region was about 75 μg/m^3, that is, above the primary annual air quality standard (50 μg/m^3), and in 1998 it was close to 50 μg/m^3, with the major contribution from mobile sources, specially diesel vehicles. Carbon monoxide concentrations also presented a decrease in the last sixteen years starting from an annual average of 8-hours mean of about 5.5 ppm in 1982 to about 3.8 ppm in 1998, but still surpassing air quality standards. Ozone is now the main problem of air pollution in the area with concentrations showing increasing tendency, from an annual average of 1-hour measurements of 35 μg/m^3 in 1981 to about 70 μg/m^3 in 1998. This increase could have been foreseen since the emissions of ozone precursors have increased in the period as showed in Tables 2 and 3. Surpassing of ozone air quality standard occurs in Sao Paulo City, mainly at the central park (Ibirapuera Park) station because of heavy traffic, and in industrial neighborhoods. In some cases the attention level is also surpassed (CETESB,2000) [2].

Data above mentioned show that air pollution control programs were very effective for SO_2 and not so effective for other pollutants. Still there is much work to do, specially in relation to transportation related sources. The main challenge, at present, is to control ozone forming processes, since this pollutant is formed at the atmosphere by complex photochemical reactions of NOx and hydrocarbons and there is not enough scientific knowledge about this process in tropical regions. Another important point is that in the city of Sao Paulo there is a strong heat island effect (Lombardo, 1985; PMSP, 1993; Ribeiro Sobral, 1996) [4] [5] [6], an increase of air temperature in the most dense urban area of about 4 to 10 degrees Celsius in relation to neighboring rural areas. The heat island is strongly related to areas where pollution levels are higher.

5 Health Effects Surveys

Surveys to assess health effects of air pollution in Sao Paulo started in 1969. This pioneer study was motivated by acute episodes of air pollution. It correlated respiratory diseases in children under 12, during a 2 years period, with air pollution levels. In the Health centers located in areas with higher levels of particulate matter in the air children were more affected by chronic bronchitis and respiratory infections (Ribeiro, 1971) [7]. The studies continued in the 1970's and registered an increase in the incidence of asthma attacks in children living in the industrial neighborhood (Alterthum, Wandalsen and Agostinho, 1975) [8].

During 1976 a survey was done through 8,000 hospital admissions and time distribution of pollution by SO_2 and particulate matter (PM) episodes. Three episodes were identified and they coincided with peaks in hospital admissions, mainly caused by respiratory and cardiovascular diseases. Children less than 4 years old were most affected (Mendes and Wakamatsu, 1976) [9].

Also in 1976 respiratory symptoms of 1,000 children living in an industrial polluted district were compared to those of 865 children living in a non-industrialized district of Sao Paulo Metropolitan region. Children from the industrialized polluted district had higher prevalence of most symptoms (Ribeiro et alii, 1976) [10].

In 1982, respiratory symptoms of 658 university students living in Sao Paulo were compared to those of 300 university students from the city of Campo Grande, a non-industrialized middle size city, located at the Brazilian mid-west. The results were similar in both groups, but smoking habit was higher among the Campo Grande students, and smoking was considered a more important etiological factor than air pollution (Nakatani et alii, 1982) [11].

Air pollution in Sao Paulo was considered an important risk factor for the elderly. Saldiva et alii (1995) [12] observed, within the city, between May 1990 and April 1991, a significant correlation between excess mortality of people 65 or more and particulate matter pollution concentration. For an increase of $100\mu g/m^3$ of this pollutant an increase in 13% of the total mortality was registered.

A correlation was also found between the intensity of the heat island in the city, associated with higher air pollution levels, and annual mortality rates related to cardiovascular and respiratory diseases (Ribeiro Sobral, 1996) [6].

Another study assessed the association between air pollution levels by PM10, SO_2, NO_2, O_3 and CO and children (under 13 years old) morbidity by prospectively collecting data on lower respiratory diseases expressed in terms of emergency visits to hospital admissions in Children's Institute of the University of Sao Paulo Medical School, along the period ranging from August 1996 to August 1997. Significant associations were observed between lower respiratory disease and all pollutants, except CO. The stronger association was found with NO2 (Farhat, 1999) [13].

Analysis of Carboxyhemoglobin (COHb) level in blood samples of male non-smoking street workers in the city of Sao Paulo, who were in downtown area for 6 months or more, indicated a positive association between higher levels of COHb in the blood and heavier traffic conditions close to their working place (Kuno, 1991) [14].

A cross-sectional and longitudinal study was conducted by this author in 1986 and 1998. The first study, in 1986, indicated a correlation between air pollution levels due to sulfur dioxide and particulate matter and respiratory symptoms in children between ages 11 and 13 in three different neighborhoods of the metropolitan region, with different pollution levels. Twelve years later the survey was repeated in the same neighborhoods in order to evaluate the impact of the pollution control programs, mentioned in the previous sections of this paper, on pollution levels and on respiratory symptoms of children belonging to the same age group, living in the same areas previously studied. The study conducted in 1986 indicated that symptoms of respiratory disease tend to increase in areas with higher pollution levels. Of 35 symptoms listed, the area with higher pollution (about 50% above primary standard during an eleven year period) showed a higher prevalence of 26 (72.2%). The area with pollution levels close to the primary standards showed a higher prevalence of seven symptoms (19.5%) and the area with low pollution levels of only three symptoms (8.4%). The difference in prevalence was bigger for the symptoms indicating worst health conditions, like cough without cold and wheezing and phlegm on most days during three months of the year. Also asthma requiring medical care and treatment, heart problems and allergies showed a much higher prevalence in the polluted areas, together with childhood diseases and ear and throat infections (Ribeiro Sobral, 1989) [15]. Twelve years later, at the area which was the most polluted in 1986, concentration of particulate matter decreased from 127 $\mu g/m^3$ in the 1973-1983 period to 65 μg/m3 in the nineties, below the primary standards. Sulfur dioxide concentrations at that area dropped from 124 μg/m3in the previous period to 40 $\mu g/m^3$ in the nineties. A decrease in the prevalence of respiratory symptoms in children was noted between 1986 and 1998. Of the 35 symptoms studied the children there showed a higher prevalence of 13 (37% as compared to 72.2% in the previous decade). On the other hand, in the area which had average concentrations of air pollution in the previous study, only sulfur dioxide control was successful, dropping from an average of 79 $\mu g/m^3$ in the period 1973-1983 to 17 $\mu g/m^3$ in the 1992-1997 period, well below the annual secondary standard. Total particulate matter concentrations increased from an average of 73 $\mu g/m^3$ in the 1973-1983 period to 124 $\mu g/m^3$ in the 1992-1997 period (more than 50% above the primary standard). The 1998 study indicated that this area had a higher prevalence of 18 symptoms out of the 35 (51% of them as compared to 19.5% in the previous study). The third area presented low pollution concentration in the two periods and lower prevalence rates of symptoms in 1986 and 1998 (Ribeiro, 2000) [16]. Symptoms decreased in neighborhood where pollution control programs were successful, but increased where only sulfur dioxide levels were reduced and other pollutants increased.

Nowadays, there is concern in relation to ozone's health effects for its concentrations surpass standards.

6 Conclusions

The evolution of air quality in Sao Paulo Metropolitan area is very dynamic and related to human and economic activities, as well as to meteorological conditions. Nevethless, public policies and programs of air pollution control have shown to be an important tool to minimize its health risks and to guarantee good quality of live to the population. The effectiveness of the programs is unequally distributed in the urban area as economic and demographic dynamics are out of control of the State Environmental Secretary. It is important that, besides emission control programs, a master environmental plan which incorporates traffic, housing and economic activities be elaborated and put in practice with community support.

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