

# Follow-up of the air pollution and the human male-to-female ratio analysis in São Paulo, Brazil: a times series study

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## ABSTRACT

**Objectives:** In order to assess if ambient air pollution in urban areas could be related to alterations in male/female ratio this study objectives to evaluate changes in ambient particulate matter (PM<sub>10</sub>) concentrations after implementation of pollution control programmes in São Paulo city and the secondary sex ratio (SSR).

**Design and methods:** A time series study was conducted. São Paulo's districts were stratified according to the PM<sub>10</sub> concentrations levels and were used as a marker of overall air pollution. The male ratio was chosen to represent the secondary sex ratio (SSR=total male birth/total births). The SSR data from each area was analysed according to the time variation and PM<sub>10</sub> concentration areas using descriptive statistics. The strength association between annual average of PM<sub>10</sub> concentration and SSR was performed through exponential regression, and it was adopted as a statistical significance level of p<0.05.

**Results:** The exponential regression showed a negative and significant association between PM<sub>10</sub> and SSR. SSR varied from 51.4% to 50.7% in São Paulo in the analysed period (2000–2007). Considering the PM<sub>10</sub> average concentration in São Paulo city of 44.72 µg/m<sup>3</sup> in the study period, the SSR decline reached almost 4.37%, equivalent to 30 934 less male births.

**Conclusions:** Ambient levels of PM<sub>10</sub> are negatively associated with changes in the SSR. Therefore, we can speculate that higher levels of particulate pollution could be related to increased rates of female births.

## INTRODUCTION

Air pollution is an environmental risk factor of concern in urban centres all over the world. Respiratory and cardiovascular diseases are the most commonly observed and associated effects followed by neoplasia.<sup>1–3</sup> However, in the last two decades lesser known effects associated to chronic air pollution exposures have started to emerge.<sup>4</sup> New epidemiological and experimental studies link exposure to reproductive adverse

## ARTICLE SUMMARY

### Article focus

- Study the potential influence of air pollution in gender in Sao Paulo in an extended time series period.
- Discuss the future impacts of imbalance gender proportionality in urban centres.

### Key messages

- Air pollution may influence gender determination.
- Scarce studies showing this effect in urban centres.
- Higher levels of air pollution may be associated to the increase rates of female births.

### Strengths and limitations of this study

- We analysed male/female births in different areas of São Paulo, Brazil.
- We compared areas with different levels of particulate matter concentration within the city.
- The analysis period has a lag concerning exposure and outcome, once the sex definition occurs during the embryonic/conception period that could not be at the same year of birth.
- Secondary sex ratio varied from 51.4% to 50.7%, suggesting that air pollution may be associated to changes.

outcomes and investigations have risen different effects to be attributed to air pollution such as low birth weight,<sup>5</sup> miscarriages,<sup>6</sup> preterm birth<sup>7</sup> and decreased sperm quality.<sup>8</sup>

Secondary sex ratio (SSR) (number of male births in relation to total births) seems to be affected in population living in polluted environments and occupationally exposed to certain chemicals.<sup>9–13</sup> Although the causality between environmental exposures and declines in SSR are still controversial, some authors suggest that the SSR as a sentinel indicator of reproductive injury and avoidable health exposures,<sup>14</sup> due to environmental pollution.

Experimental evidence indicate that prenatal exposure to air pollution derived from diesel exhausts is associated with altered sexual differentiation and function.<sup>15</sup> Studies in humans and animals have found a reduction in the number of male births associated with lower male fertility, but the mechanism by which environmental hazards might change the sex ratio has not yet been established.<sup>9 16</sup>

In a previous study, we have demonstrated a significant negative association between the sex ratio at birth or SSR and ambient levels of particulate matter (PM<sub>10</sub>).<sup>16</sup> This study was conducted in São Paulo Metropolitan Region (SPMR) in Brazil, and the area was divided in terms of level of PM<sub>10</sub> concentrations. Findings indicated a SSR of 51.7% for the less-polluted area whereas for highly polluted area the ratio decreased to 50.7%. This result corresponds to a difference of 1% in total male births, or 1180 fewer male births in the most polluted regions).<sup>16</sup>

Previous data analysed a restricted time series period (2001–2003) and during the last years air pollution levels in the city has changed significantly due to the national pollution control programme (PROCONVE and PROMOT). In this sense, it is desirable to verify if changes in levels of air pollution are accompanied by concurrent changes in the SSR in SPMR. Thus, the purpose of this study was to extend the time period evaluating from 2000 to 2007 to assess changes in ambient particulate matter (PM<sub>10</sub>) concentrations and SSR in the RMSP during this period (SRR).

## METHODS

### Number of births according to gender

The total number of live births in São Paulo was collected from 2000 to 2007 on a monthly basis representing a sample of 53 612 births. These records were obtained from SEADE, a public foundation which registers population data in the State of São Paulo. The male ratio was chosen to represent the SSR (SSR=total male birth/total births).

### Studied area

São Paulo is the largest Brazilian city, where most important economic activity is concentrated and is responsible for 17% of the country's gross national product. São Paulo is considered the sixth largest city in the world with a population of approximately 11 million in an area of 7943.82 km<sup>2</sup>.<sup>17</sup>

According to the São Paulo's Environmental State Agency air pollution is derived mostly by vehicles (combustion and resuspension) and a small industrial contribution. Winter period in São Paulo favours thermal inversions and this may also contribute to non-favourable pollutant dispersion scenario and increased levels of PM<sub>10</sub>.<sup>18</sup> Air pollution control programmes in São Paulo Metropolitan Area are well succeed for the

fixed sources however the mobile sources are of government concern.

### Air pollution data

The studied area encompasses the subdistricts where the state environmental agency (CETESB) has air monitoring stations, and were selected according to different air pollution gradients (high and low concentrations' areas). In the case of São Paulo we have a well spread air pollution monitoring system thus we assumed that the concentration of a given region would reflect somehow the exposure. Since we have information about birth outcomes aggregated by administrative districts in São Paulo, we assumed that the station located in a given districted would reflect the exposure of pregnant women living in that given district. We did not have access to information about maternal mobility during gestation. We assumed that pollution affects the mothers independently. We included districts for which we had good-quality representative data (valid time series) and stratified according to the PM<sub>10</sub> levels. The districts were aggregated according to the level of PM<sub>10</sub> concentration as follow: high ( $\geq 40 \mu\text{g}/\text{m}^3$ ) and low levels ( $< 40 \mu\text{g}/\text{m}^3$ ). PM<sub>10</sub> concentrations were used as a marker of overall air pollution.

In total data were obtained from five automatic monitoring stations maintained by CETESB. In all stations, PM<sub>10</sub> was measured through inter compared  $\beta$  radiation monitors. The daily values obtained from each station were averaged in a monthly basis and considered as indicative of city-wide pollution levels. There is a correlation between PM<sub>10</sub> concentrations registered at the different sites that means that PM<sub>10</sub> is regularly distributed along the citywide.

### Statistical analysis

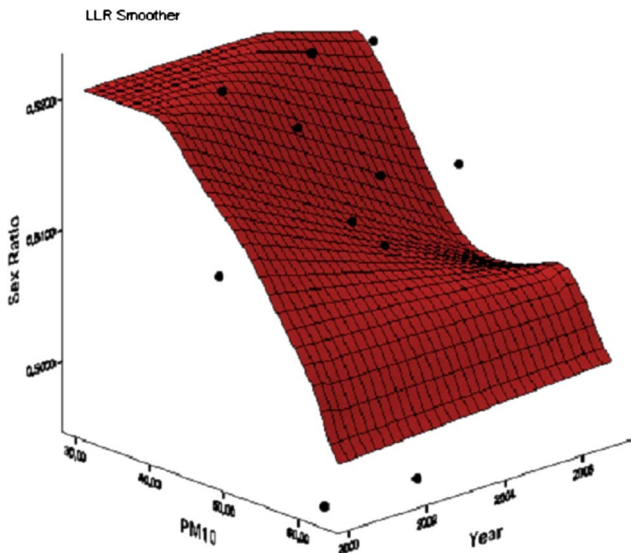
The SSR data from each area were analysed according to the time variation and PM<sub>10</sub> concentration in the areas using descriptive statistics. The strength association between annual average of PM<sub>10</sub> concentration and SSR was performed through exponential regression, and it was adopted a statistical significance level of  $p < 0.05$ .

## RESULTS

The subdistrict's average concentrations of PM<sub>10</sub> in the period ranged from 34.1 to 64  $\mu\text{g}/\text{m}^3$  and the SSR from 0.49 to 0.52 as depicted in figure 1.

In the less polluted area, the SSR average was 51.4% for 28 022 births recorded whereas in the most polluted area the ratio decreased to 50.7% for 22 590 births recorded. We observed a general decrease trend in PM<sub>10</sub> concentrations through the analysed time period while the SSR simultaneously presented an increase.

An analysis of percentage variations considering the extreme years of the time-series analysis (ie, 2007 compared to 2001) was conducted showing a continuous decrease of PM<sub>10</sub> concentration associated to an



**Figure 1** Relation between sex ratio and particulate matter in the period (2000–2007).

increase in SSR in each monitoring subdistrict in the period, except for one monitoring station, which presented the same average level (figure 2). Surprisingly, Cambuci (CBC) monitoring station presented no variation in both variables (PM<sub>10</sub> and SSR); however, this finding confirms the association observed in the other stations where lower PM<sub>10</sub> concentrations are related to higher SSR.

The exponential regression showed a negative and significant association between PM<sub>10</sub> and SSR (table 1).

Figure 3 emphasises the inversely relationship of PM<sub>10</sub> concentrations and SSR, specially from 2002 on, when we can observe the annual variations in both variables occurring in opposite directions, reinforcing the above demonstrated findings.

**DISCUSSION**

In this study we have evaluated the variation in PM<sub>10</sub> environmental concentration and SSR in the Metropolitan Region of Sao Paulo, Brazil during the years of 2001–2007. In a previous study conducted in the same area we have

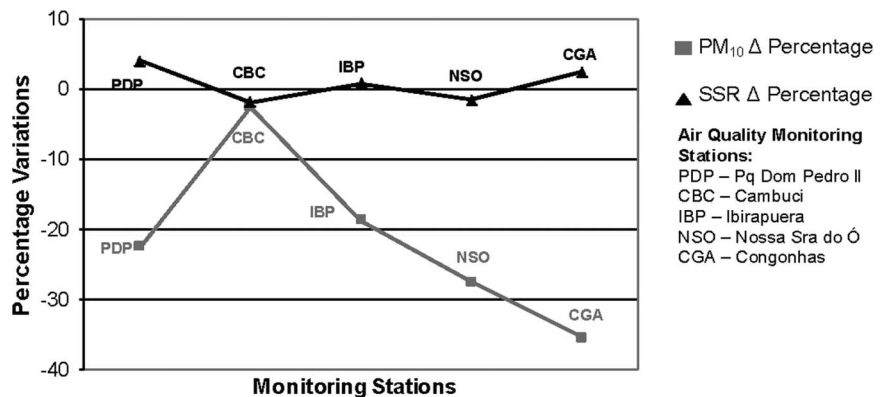
noted that there was a significant negative association between the sex ratio at birth or SSR and ambient levels of particulate matter (PM<sub>10</sub>).<sup>16</sup> In this study we extended analysed time period, which allowed us to observe improvements in air quality due to the environmental control politics introduced (motorised vehicles’ emissions control) and in the population’s gender pattern. Although the air quality increased we still find a significant negative association between the SSR and PM<sub>10</sub> concentration.

Assessments of emissions source of the particulate air pollution in São Paulo city conducted by CETESB (São Paulo Environmental State Agency)<sup>18</sup> and several studies conducted in São Paulo,<sup>19 20</sup> using the receptor models and chemical comprehensive characterisation of particles have indicated that 90% of PM<sub>10</sub> is generated by vehicles or photochemical process. PM<sub>10</sub> should not be considered a single pollutant; it is a synthesis of air pollutants, carrying primary and secondary pollutants, its composition includes carbon and many other chemicals depending on its emission source. In the referred stations there were an improvement of the diesel fuel and motors’ technology, added by a traffic detour due to an implementation of a road infrastructure (this behaviour was observed in PDP station).

In one region of the city, where CBC station is located (central area of São Paulo city) no variation in PM<sub>10</sub> was noted and we can speculate that this no variation in PM<sub>10</sub> is due by the fact that this area has buses emissions as main air pollution source, with lower contributions from cars and motorcycles. No variations in PM<sub>10</sub> in this region shows that air pollution control programme have not positively impacted the area leading to the maintenance of the air pollution level. Maintenance of PM<sub>10</sub> levels was accompanied by maintenance of the SSR for this region. CBC station records and associated SSR can be interpreted as a control unit for other stations where there were variations in PM<sub>10</sub> concentration meaning that for the same level of air pollution the same SSR was registered.

These results could suggest that there is a possible contribution of PM<sub>10</sub> levels in SSR variation, explaining more than 30% of the events. If we consider that there

**Figure 2** Particulate matter and secondary sex ratio percentage variations in the period (2000–2007) for the different monitoring station.



**Table 1** Bivariate exponential regression analysis and relative risk

| Variable | R <sup>2</sup> | β      | p Value | RR    |
|----------|----------------|--------|---------|-------|
| SSR      | 0.322          | -0.001 | 0.022   | 0.999 |

RR, relative risk; SSR, secondary sex ratio.

is causal relationship the increase of 10 µg/m<sup>3</sup> in PM<sub>10</sub> concentration would lead to a decline of 0.995% in SSR. Further, taking into account a PM<sub>10</sub> average concentration in São Paulo city of 44.72 µg/m<sup>3</sup> in this study period the SSR decline would reach almost 4.37% which is equivalent to 30 934 less male births.

This behaviour (decrease in PM<sub>10</sub> and increase in SSR) is consistent with previous findings,<sup>15</sup> that have shown a possible association between exposure to urban air pollution and imbalance of the sex ratio at birth. Other studies have also reported lower sex ratio in residential areas at risk from air pollution emitted from incinerators<sup>21</sup> as well as higher sex ratio in areas exposed to polluted air from steel foundry.<sup>22</sup>

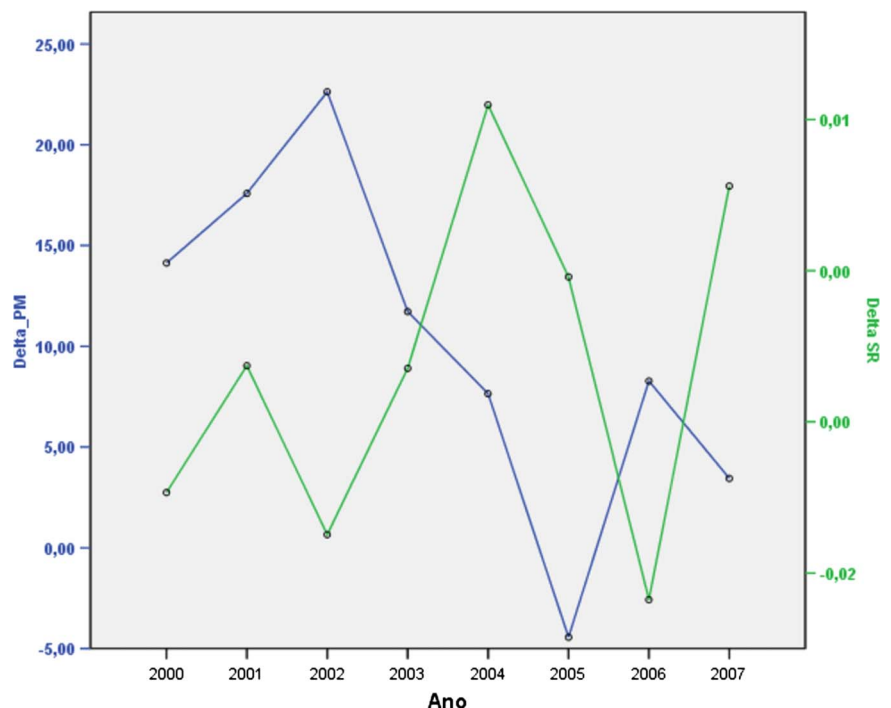
In humans the sex of the baby is determined primarily by the fecundation of the X egg by the X (female) or Y (male) sperm. In the case of environmental exposures and changes in the SSR as a health outcome, it is very difficult to determine the time connection between gender at birth because the effect could have occurred even before pregnancy. Further, changes in the sex ratio may be associated with maternal or paternal factors or with both. Preimplantation hypothesis proposes that in some circumstances there are more favourable development or survival of X or Y bearing sperm or survival of male or female embryos.<sup>23-25</sup> In a previous study of our

group we have shown that exposure to PM during the preconception period are associated to early pregnancy loss in women undergoing in vitro fertilisation<sup>26</sup> and thus there is also another possibility to explain the changes in sex ratio by sex specific increases in intrauterine death or stillbirth.

Potential toxicological mechanisms that might explain and give strength to the environmental contamination causes in the determination of the sex ratio are still inconclusive. There are some suggestions in the literature that include the hormonal status of the parents at the time of conception, differential characteristics and sensibility of sperm of one sex, combination and presence of specific toxic substances (PAH, dioxin).<sup>27-28</sup> Although we have not evaluated the elemental composition of PM<sub>10</sub>, previous studies have characterised the composition of these particles from São Paulo city. Chemical elements included Fe, Br, Al, Si, S, Cu, Zn, Pb<sup>29</sup> and PAH such as benzene, toluene, etil-benzene and xylene.<sup>30</sup> Toxicological studies have shown that certain toxicants present in ambient air pollution, such as PAH and heavy metals potential endocrine disruptors.<sup>31-32</sup>

This is a descriptive study which does not intend to implicate in causality and it subsidises on a previous research.<sup>16</sup> The changes in air pollution were compatible with the effects' variation and there is a toxicological support for that.<sup>16</sup> In this sense, it is a limitation but once it is a trend study and the measures to be aggregated are monthly records (SSR) and daily measures (PM<sub>10</sub>), a synchrony between exposure and gender determination is minimised when you aggregate data on yearly basis. This is a different situation from a classical time series study because you know exactly the time

**Figure 3** δ particulate matter and δ secondary sex ratio percentage variations along the analysed period (2000–2007).



relationship between exposure and health outcome (death or hospital admission). In the case of considering SSR as a health outcome, it is very difficult to determine the time connection between exposure and sex at birth; as previously demonstrated it can occur before conception, during embryonic implantation or gestation. When you aggregate the data on a yearly basis you encompass these phases, therefore in a times series study we cannot capture this effect. It could be done in a birth cohort study but once these prematurity are scarce events, the size of the sample would become a complex and costly study.

Increasing differences in the male/female ratio at birth could lead, in a mid-to-long-term future, to a deficit in male population and probably cause social problems. This scenario gets worse if we consider that men are more prone to premature death because of their trend to engage in risk behaviour and violence.<sup>33</sup>

The air pollution control programmes (PROCONVE and PROMOT, which refers to emissions limit to new motor vehicles—cars and motorbikes) may have contributed to the improvement in the air quality parameters registered through the decade. Recently, an inspection and maintenance programme concerning emissions limits for the old and second hand vehicles was implemented in São Paulo and that may also have favoured this scenario. Our findings are important indicators for an advance of the public health endpoints due to the improvement of the air quality in urban centres. Considering the disproportion in the male/female births, this balance is desirable to achieve and maintain in all populations of urban centres. Furthermore, the abatement of air pollution is a target that governments must pursue.

## CONCLUSIONS

Although the biological mechanisms responsible for the SSR changes are not clearly established, this study indicates that concentration of particulate air pollution in urban cities are associated with decreased SSR. Also, this data give support for the use of SSR as a potential indicator of the negative health impacts of fuels combustion derived emissions in urban cities.

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**Contributors** MMV has contributed to the Introduction section. SGEKM, FR-S, LA-L and PHNS were involved in data collection and statistical analysis. SGEKM defined the study design. All authors have contributed to the revised final version of the manuscript and to the discussion section.

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