The effect of air pollution on children's health: a comparative study between La Plata and Bahía Blanca, Buenos Aires Province, Argentina

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Abstract

We present the results of a study of outdoor air quality in two comparable regions of Buenos Aires province (Argentina); La Plata and Bahía Blanca, developed jointly by researchers of the National University in both cities, and of the Hospital of Bahía Blanca, between 2009 and 2011. Both regions are characterized by a large petrochemical complex and a village with outstanding traffic. In this study, we measure levels of volatile organic compounds (VOCs), particulate matter suspended in air (PM) in air outdoor and affectation of respiratory system in children between 6 and 12 years. Also, analysis of the effect of the air pollution exposure was made through the calculation of potentially increased life time cancer risk (LCR) in children. In both regions, including three areas: urban, industrial and residential (reference area), 20 VOCs were sampled by passive monitoring (3M 3500), and determined by GC/FID, comprising n-alkanes, cycloalkanes, aromatics, chlorinated compounds,

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terpenoids and ketones; particulate matter (PM10) was token using a low flow sampler MiniVol TAS, and spirometry were performed, using a portable spirometer.

The collected data show higher levels of PM10 in Bahía Blanca, both in the industrial zone and urban areas, the industrial area of Bahía Blanca with very bad air quality, associable with a 5% increase in mortality. The levels of total VOCs found in the residential area for both regions are comparable. Spirometry parameters of children living in an industrial area evidence respiratory disease with respect to urban and residential areas.
Keywords: air pollution, VOCs, PM, spirometry.

1 Introduction

Air pollution is a major threat to public health worldwide. According to the World Health Organization (WHO), more than two million premature deaths per year are attributable to the effects of outdoor and indoor air pollution. More than half of the disease burden falls on the populations of developing countries [1, 2].

Numerous epidemiological studies show as chronic exposure to traffic-related pollutants and the chemical and petrochemical industry, such as particulate matter (PM), metals, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs) and inorganic gases (SO_2 and NOx), adverse effects to the development and lung function, often expressed in terms of asthma or chronic obstructive pulmonary disease (COPD), and increased mortality mainly in children. It is therefore important to characterize and quantify air pollution, recognize and assess the associated health effects and characterize emission sources [3–6].

Therefore, it is essential to know the levels of VOCs and PM in outdoor environments to associate with observed health effects. Also, to evaluate the health impact on children and adults related to changed levels of VOCs, indicators of risk assessment were used as the lifetime cancer risk (LCR_{ij}) [6–9]. In this context we present the results obtained during 2009 and 2011 in separate monitoring campaigns VOCs and PM in the regions of La Plata and Bahía Blanca.

2 Methodology

2.1 Sampling and sampling sites

The regions of La Plata and Bahía Blanca share several common characteristics: demographic populations and socially similar and prominent commercial, administrative, educational and productive activity. In both districts are located petrochemical poles, about 5 km distance from the capital city, with outstanding production volumes. In both regions, as the main emission sources and methodology applied to working child population are selected three types of areas [6, 10–14]:

- Industrial area: adjacencies of Petrochemical Pole, industrial emissions.
- Urban area: main source of vehicular emission.
- Reference area: areas outside the city (residential).

Monitoring was developed during 2009–2011.

VOCs were sampling placing 44 passive organic monitors (3M 3500) outdoor in family homes and schools in the various areas, in both regions, for 30 days. In all cases prepared to cover from the rain, from 1.5 to 2 meters.

PM was sampled outdoor using a low flow sampler MiniVol TAS for five days, in the different areas, in both regions.

Spirometry analysis was done with a portable spirometer in a group of 211 children, between 6 and 12 years, chosen randomly from the different areas in both regions.

2.2 Analytical methods

2.2.1 VOCs analysis

After exposure the VOCs were desorbed from the adsorption layers (charcoal pads) by means of 1 ml of the mixture composed of CH2Cl2 : CH3OH (50:50). They were all subjected to mechanical agitation (10 min, 60 cycles min^{-1}. 20 VOCs were analyzed (n-hexane, n-decane, n-dodecane, cyclohexane, methylcyclohexane, trichlorethylene, tetrachlorethylene, methylethyl ketone, methylisobutylketone, 2-hexanone, benzene, toluene, ethylbenzene, m-xylene, p-xylene, o-xylene, styrene, naphthalene, cumene, and limonene), calibrated with standards thereof [13–16].

The analysis methodology consisted of: series Agilent 6890N gas chromatograph, Zebron ZB-624 column 30 m x 320 µm x 1.80 µm, FID detection (250°C), temperature ramp: 35°C, 7 min; increase 4°C min^{-1} to 80°C for 1 min, new ramp 6°C min^{-1} to 160°C for 3min. Total time 36 min. Injector split mode (1:1 ratio, 145°C), hydrogen carrier, column flow rate 3.7 mL min^{-1}, data acquisition program ChemStation revision A.08.03, as described in other studies before. The recovery rate in spiking experiments was between 66 and 103% [14–16].

The range of linearity for the system used (GC-FID) is between 1 and 100 mg L-1 on the injection. The average concentration of each component C (in mg m^{-3}) during the sampling interval was calculated according to the formula adopted in the Application Bulletin 3M [18]: C = m A/r t; where m is the total mass of adsorbed pollutant (in mg), t is the sampling time interval (in minutes), r recovery factor and A is a constant that includes the diffusion coefficient of the contaminant, the area of diffusion of activated carbon pad and the diffusion distance inside the sampler 3M [15–17].

2.2.2 PM analysis

Sampling and analysis of particulate matter was done in respirable fraction (particles <10 µm) using a sampler MiniVol TAS, about 5 days per zone. The content in each sample was determined gravimetrically [6, 14, 16].

2.2.3 Spirometric analysis

A randomly selected group of 211 children, between 6 and 12 years, had lung function measured by means of standard spirometry. Children were then chosen randomly by the technician, who was blind to questionnaire data. The analysis of the results was performed using standard methodology. This group included 53 (25.1%) children from industrial, 86 (40.8%) from urban, 72 (34.1%) from residential areas of both regions [10, 12, 17–19].

Lung function was measured in the afternoon (1–5 PM) according to American Thoracic Society guidelines. A portable spirometer (Datospir 120A; Sibelmed, Barcelona, Spain) coupled with computerized data acquisition software was used. The following variables were obtained from the best of 3 reproducible forced expiratory manoeuvres: forced vital capacity (FVC), forced expiratory volume in 1 second (FEV1), and FEV1/FVC ratio [12, 18, 19].

2.2.4 Health risk assessment

To evaluate the health risk for the people living in the investigated regions, the Lifetime Cancer Risk (LCR) index was analysed for the potential carcinogenic compounds benzene (IARC group 1, carcinogenic for human). The risk was expressed by multiplication of the chronic daily intake (CDI) and the IRIS system potency factor for the carcinogenic compounds (IRIS: Integrated Risk Information System) [6, 10, 20]. The CDI was calculated with the following equation:

$$CDI = \frac{CC \ x \ IR \ x \ ED \ x \ EF \ x \ LE}{BW \ x \ ATL \ x \ NY}$$

where CC is the contaminant concentration (mg m^{-3}). The participants in our study were children with an average age of 10 years (reflecting the value for the highest duration of exposure, LE), and an arithmetic mean in body weight (BW) of 35 kg. A daily inhalation rate (IR) of 10 m^3 was assumed [20–22]. Because the people were the most time of the day indoors, exposure duration (ED) of 18 hours per day was guessed for indoor exposure and 6 hours per day outdoors with an exposure frequency (EF) of 52 weeks per year. ATL is the average time of lifetime (period over which exposure is averaged, 70 years were used); and NY the number of days per year (365 days) exposed [6, 10, 21–23]. The absorption factor of the VOCs for human was supposed to be 90%. The USEPA developed IRIS to define the values of potency factors (PF in (mg/kg/day)-1) for selected VOCs, for benzene PF = 0.029 [24].

3 Results and discussion

First emphasizes that total VOCs and alkanes levels of Bahía Blanca (BB), for all areas, are higher than those for La Plata (LP). BTEX level are similar for both regions, for residential and industrial areas, but level of urban BTEX of BB was 3.8 times higher than urban LP.

Figures 1, 2 and 3 show the median (mgm^{-3}) of the values found for both regions in each area, and the families of compounds plotted were defined as follows:

- Alkanes: n-hexane, n-decane, n-dodecane, cyclohexane, methylcyclohexane.
- Aromatics: benzene, toluene, ethylbenzene, (o, m, p) xylenes, styrene, naphthalene.
- BTEX: benzene, toluene, ethylbenzene, (o, m, p) xylenes.
- Chlorinated: trichlorethylene, tetrachlorethylene.
- Ketones: methyl ethyl ketone, methyl isobutyl ketone, 2-hexanone.
- Terpenes: cumene, limonene

In industrial areas VOCs values in Bahía Blanca of alkanes and total VOCs prevail (2.7 times), while BTEX have comparable levels between LP and BB (see Fig. 1). However, the relative contribution of these families were diverse: the contribution of the BTEX on total VOCs was 48.4% in LP but 15.8% in BB, however the contribution of the alkanes on total VOCs are similar for both regions, in about 55%. Since the sum of the concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX) is recognized as an indicator of emissions from vehicular traffic, this analysis suggests the high relative weight of the contribution of vehicular transit in La Plata, less in Bahía Blanca, always in the Industrial area. In the same way can be read the relationship BTEX/alkanes in both regions, 0.91 (LP) and 0.26 (BB).

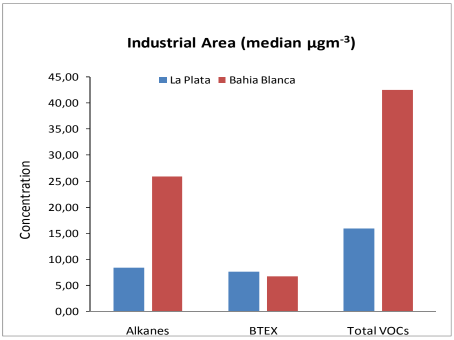

Figure 1: VOCs concentration grouped by families in industrial area.

In urban areas, Bahía Blanca presents higher values for all family of compound analyzed, in similar proportions: alkanes 3.0 times, BTEX 3.3 times and total VOCs 4.5 times respect to La Plata (see Fig. 2).

It is interesting to note that the contribution of the BTEX on total VOCs was not similar, but not as dissimilar as occur in industry. In this case, BTEX contribute with 46.3% and 33.8% for LP and BB, respectively; and alkanes with 38.2% and 25.5%, in the same order. This analysis suggests similar contribution of vehicular transit in both regions for urban area. In effect, the relationship BTEX/alkanes in both regions are similar in about 1.2 times.

Finally, referring to residential areas, VOCs values in Bahía Blanca of alkanes and total VOCs prevail (1.6 and 2.2 times respectively), while BTEX have comparable levels between LP and BB (see Fig. 3). However, the relative contributions of these families were diverse: the contribution of the BTEX on

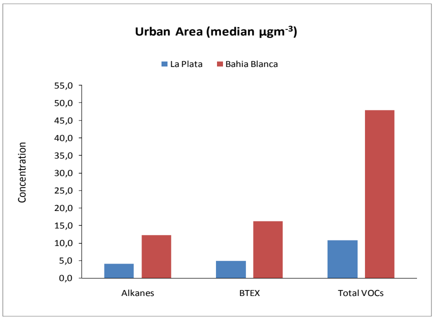

Figure 2: VOCs concentration grouped by families in urban area.

total VOCs was 58.7% in LP but 25.2% in BB, however they show similar relative proportions for alkanes on total VOCs for both regions (54.5% and 39.4%, respectively).

Regarding the relationship BTEX/Alkanes, contrary to what was observed for the urban area, while LP indicates similar proportions (0.92), for BB the predominance of alkanes are noticeable (0.64). This analysis indicates the relative weight of the contribution of vehicular traffic in La Plata, much less in Bahía Blanca, always in the residential area, perhaps related to the strong wind in BB.

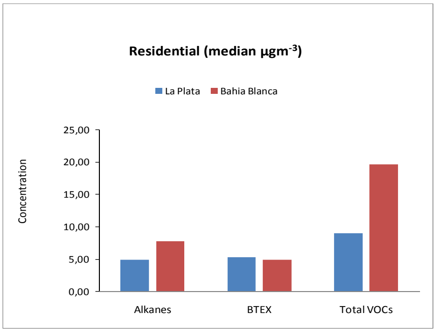

Figure 3: VOCs concentration grouped by families in residential area.

Interestingly, while generally seen in La Plata lower VOCs values, this situation is the result of an agreement between the petrochemical companies and the Provincial Agency for Sustainable Development (OPDS). Indeed, if the values found in Bahía Blanca were compared with those of La Plata during 1999–2002, could be seen as the latter are of greatest value, reversing the comparative situation (see Fig. 4). That is, the levels of VOCs in La Plata declined after the effective action of the regulatory body, and this could also be observed in Bahía Blanca levels known to be found there [10, 13, 14].

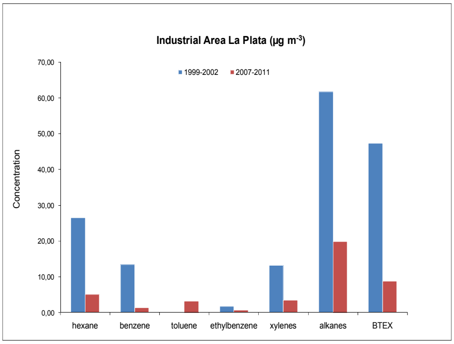

Figure 4: Comparatives level of VOCs in Industrial area (La Plata) between 1999–2002 and 2007–2011.

Regarding particulate matter (PM10), we see that the levels for Industrial and Urban area in Bahía Blanca are superior respect to same areas in La Plata; while concentrations in residential area are comparable (see Table 1).

Table 1: PM10 levels for region and different areas.

Area	**Bahía Blanca (µg m^{-3})**		**La Plata (µg m^{-3})**	
	Median	Maximum	Median	Maximum
Industrial	177.8	179.5	91.9	142.3
Urban	97.2	176.4	50.2	57.4
Residential	34.6	52.9	28.7	73.0

Significant levels of PM10 observed in Bahía Blanca for industrial and urban areas, is probably associated with high levels of suspended material from soil and other products of some companies in the industrial zone, as fertilizer factory, and some bins grains, and the strong winds typical of the region. In fact, the last values of PM10 in the industrial area of La Plata, where some big movements of the upper layers of soil to carry out the construction of a new thermal plant and a new route, have also shown a marked increase, as seen in Table 2, which shows levels 2–3 times higher than PM in 1999–2002 [10, 13, 14].

Given the international experience regarding the known effects associated with exposure to VOCs and PM, with this image of the levels of contamination found, it is important to analyze the possible associated health effects, in order to assess the consequences associated with this level. From this perspective, we first present the results obtained from the study of respiratory parameters in children aged 6–12 years in both regions. These data, showed as medians and standard deviations of respiratory parameters surveyed, are presented in Table 3.

The observation of the data related to lung function parameters, indicating no substantial differences between the values found for the different areas in each region. This is important, because beyond treated in the case of Bahía Blanca a

Table 2: PM10 levels for La Plata for different areas in two periods.

Area	PM10 La Plata ($\mu g\ m^{-3}$)	
	1999–2002	2009–2011
Industrial	33.8	91.9
Urban	26.9	50.2
Residential	10.6	28.7

Table 3: Prevalence of adverse respiratory outcomes compared for each area of La Plata and Bahía Blanca.

		FVC (% predicted)	FEV1 (% predicted)	FEV1/FVC (% predicted)	Age (years)	Weight (kg)	Height (cm)	Gender (% male).
La Plata	n=194							
Industrial	51	86.7 (22.4)	98.8 (23.8)	95.1 (7.9)	10	36,0	142,0	42,3
Urban	78	92.3 (24.8)	101.6 (23.2)	95.1 (7.9)	10	35,0	140,0	35,1
Residential	65	84.4 (17.1)	99.5 (18.4)	100.9 (5,4)	10,0	37,0	140,0	45,5
Bahia Blanca	n=17							
Industrial	2	86.8 (51.6)	82.0 (40.3)	98.1 (11.9)	9	35,0	137,0	50,0
Urban	8	108.2 (39.4)	106.0 (37.9)	99.8 (19.8)	9	32,7	133,0	62,5
Residential	7	86.3 (31.8)	94.0 (27.2)	106.4 (6.5)	8	30,3	130,0	71,4

Note: Lungs functions data are presented as groups median (SDs).

small number of surveys, situation that is evident in the accompanying standard deviations each value, because in previous studies by various authors, and even of our group in the previous period in La Plata, with higher values of VOCs in the industrial area, allow showed significant differences between the values of respiratory parameters of different areas correlated with high exposure levels [12, 25–27].

The other important element regarding potential health effects is the level of exposure to benzene, since it is a carcinogenic substance. In this sense, the median concentration of benzene found in the two regions and respective different areas were very similar, around 0.85 (0.69–0.96) μgm^{-3}. This value is lower than others founded in some European cities, as Birmingham (3.3 μgm^{-3}), Cardiff (3.9 μgm^{-3}), Edinburgh (2.3 μgm^{-3}), Bristol (4.0 μgm^{-3}), London (3.5 μgm^{-3}), Liverpool (2.9 μgm^{-3}), Copenhagen (2.9 μgm^{-3}) and Toulouse (1.1–2.0 μgm^{-3}) [28, 29]; and also much lower than in some cities in Africa and Asia such as: Ramsis (87.2 μgm^{-3}), Haram (46.2 μgm^{-3}), Hong Kong (10.1–15.1 μgm^{-3}) and Suzhou (7.2–13.3 μgm^{-3}) [30, 31].

The results showed a LCR outdoor of similar order of magnitude for children of both regions (Table 4). The World Health Organization (WHO) considered as acceptable a LCR between 1×10^{-5} to 1×10^{-6}, whereas value lower than 1×10^{-6} is recommended by USEPA [6, 9, 20, 24]. In this sense, for all children groups, the values of LCR calculated are under the limits proposed for both, WHO and US EPA.

Table 4: Prevalence of adverse respiratory outcomes compared for each area of La Plata and Bahía Blanca.

	Industrial	**Urban**	**Residential**
La Plata	Benzene	Benzene	Benzene
LCR ***1999-2002***	3.6 E-06	8.9 E-07	4.4 E-07
LCR ***2007-2011***	2.2 E-07	2.6 E-07	2.3 E-07
Bahía Blanca	Benzene	Benzene	Benzene
LCR ***2009-2011***	1.8 E-07	1.9 E-07	2.2 E-07

Another possibility regarding the impact of air pollution on children's health is to analyze the levels of PM compared to levels guide for air quality of WHO or European legislation. In Table 5 are situated PM levels found in the three areas of La Plata and Bahía Blanca with respect to levels above the guide.

Table 5: Concentration of PM10 compared to levels guide for air quality.

PM10 range (μgm^{-3})	**Quality**[a]	**Pollution level**[a]	**Mortality increment**[b]	**Experimental data**
0–25	Excellent	Low		
25–50	Good	Normal	0	Residential LP (28.7); BB (34.6)
50–75	Poor	High	1.2%	Urban LP (50.2)
75–100	Bad	Very High	2.5%	Industrial LP (91.9); Urban BB (97.2)
100–150	Very Bad	Very High	5%	Industrial BB (177.8)

[a]European legislation [32].
[b]WHO guidelines for Europe [33].

As can be seen, for both regions residential area PM10 levels are good, for urban area of La Plata concentration is situated in the area of poor quality, with a 1.2% increase in infant mortality; the industrial area of La Plata and urban area of Bahía Blanca are placed into the bad quality range, with a 2.5% increase in mortality; and finally, the industrial area of Bahía Blanca is located into the very bad quality level with an increase of 5% mortality.

While it is necessary to identify different types of particulate matter, due to the availability of multiple sources (combustion processes, industrial furnaces, petrochemical processes, grain silos and fertilizer production), and even the identification and quantification of adsorbed polycyclic aromatic hydrocarbons and metals, concentrations of PM10 in Bahía Blanca are very high and require new measurements and a significant process control.

Finally, although this requires further monitoring, especially of particulate matter in Bahía Blanca, to improve the statistical analysis and establish clear patterns of contamination; also it would be very important to complete the survey spirometric, incorporating a larger number of children in BB, so as to establish a clear quantitative comparison, accompanied by the respective statistical analysis are clear similarities and differences found in each site, as well as increased health risks in Bahía Blanca.

4 Conclusions

In this paper we compare the results of air quality by VOCs and PM10 determination between two comparable regions (La Plata and Bahía Blanca), each with three different areas depending on the sources of contaminants: urban, industrial and residential areas.

The comparative analysis of VOCs data show a great similarity in the levels found in both regions in the three areas; being higher in all cases the values for the industrial area, also found a strong influence of road traffic in urban areas. Furthermore, benzene levels were comparable with those found in several European cities, but lower than Asian locations, and the LCR calculation demonstrates acceptable values for WHO and the US EPA the criteria.

Spirometric studies were conducted in children from 6 to 12 years, founded no significant differences between the two regions, and requiring further study mainly in Bahía Blanca, to have a greater number of data for complete statistical analysis.

With respect to particulate matter, Bahía Blanca levels in all cases were higher than La Plata, predominantly high values in the industrial area, the extreme case being obtained in industrial area of Bahía Blanca with very bad air quality, associable with a 5% increased in mortality (see table 5).

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