Environmental Science and Pollution Research (2018) 25:10039–10048
https://doi.org/10.1007/s11356-018-1265-2

RESEARCH ARTICLE

Characterization and cancer risk assessment of VOCs in home and school environments in gran La Plata, Argentina

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Received: 6 November 2017 / Accepted: 11 January 2018 / Published online: 29 January 2018

Abstract

Three areas are highlighted in Gran La Plata, Argentina: industrial, urban, and residential. In this work, the levels of volatile organic compounds (VOCs) in indoor air of homes and schools in those areas were analyzed, through the use of passive monitors. The study period is between 2007 and 2010. Higher levels of VOCs were found in homes and schools in the industrial zone, higher than the levels corresponding to urban and residential. Taking into account the relationship between indoor and outdoor levels of VOCs, they have ratios (I/O) between 1.5 and 10 are evidenced contributions of emission sources of VOCs both indoor and outdoor. Complementarily, we estimated the life time cancer risk (LCR) for benzene, styrene, trichloroethylene, and tetrachloroethylene in children who spend their time mostly in such indoor environments. The results show high LCR values for benzene, which exceed acceptable values for the US EPA.

Keywords VOCs · LCR · Health risk · Indoor

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 air pollution in outdoor and indoor urban areas. More than half of the disease burden falls on the populations of developing countries (OPS 2007; WHO 2009; Khare 2012).

Air pollution and its effects on humans are a growing concern for public health. Wide variety of pollutants found in the air in the form of gases, volatile compounds, aerosols, or particulate matter from human activities (OPS 2007; WHO 2006a, b, 2010).

The VOCs include a large group of air pollutants such as benzene, toluene, xylene, styrene, hexane, heptane, trichloroethylene, perchloroethylene, and cyclohexene, etc. Its exposure is associated with allergies and adverse respiratory effects expressed as asthma or chronic obstructive pulmonary disease (COPD) (Tanaka et al. 2000; Leikauf 2002; Weisel 2002; Gauderman et al. 2002; Elliott et al. 2006; Adgate et al. 2004).

VOCs contribute to the most serious air pollution problems. First, they have proved active in the formation of smog and ground level ozone production. Secondly, there are several VOCs to which they can be classified as carcinogenic. Benzene and trichloroethylene has been classified as a known human carcinogen by the International Agency for Research on Cancer (IARC) based on evidence from epidemiologic studies and animal data (IARC 1987; 2012) and the styrene and tetrachlorethylene are classified as possible or probable carcinogen for human, respectively (IARC 1995, 2002).

Studies on indoor pollution are important since children spends more than 80% of the daytime in the indoor environment either in the home or school (Guo et al. 2004; Ohura et al. 2006; Wang et al. 2007). Particularly, the determination of indoor VOC levels is of great importance because they can

Responsible editor: Philippe Garrigues

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cause potential effects on the people in such environments either short-term effects or long term. Their levels may be influenced by outdoor levels, indoor volume, ventilation rates, seasonal factors, dry cleaning products, furnishing, and human activities such as hobbies, printing, painting, use of building materials, etc. (Srivastava et al. 2000; Son et al. 2003; Pankow et al. 2003; Schlink et al. 2004; Ohura et al. 2006; Caro and Gallego 2009).

While some indoor VOCs originate exclusively from indoor sources, others have multiple indoor and outdoor sources. According to several authors (Wolkoff 1995; Jones 1999; Bluyssen et al. 1996; Salthammer 1999; Wilkins 2002; Ohura et al. 2006; Caro and Gallego 2009) the main sources of the typical indoor VOCs together with the major VOC chemical classes associated with the sources are summarized in the following:

- Outdoor sources: traffic, industry (aliphatic and aromatic hydrocarbons, aldehydes, ketones, esters).
- Building material: insulation, paint, plywood, adhesives (aliphatic and aromatic hydrocarbons, alcohols, ketones, esters).
- Furnishing material: furniture, floor/wall coverings (aliphatic and aromatic hydrocarbons, alcohols, halocarbons, aldehydes, ketones, ethers, esters).
- Garage and combustion appliances: vehicle emission, tobacco smoking, candles (aliphatic and aromatic hydrocarbons aldehydes, amines).
- Consumer products: cleaning, personal care products (aliphatic and aromatic hydrocarbons, alcohols, halocarbons, aldehydes, ketones, terpenes, ethers, esters).
- Equipment: printers, photocopiers, computers, other office equipment (aromatic hydrocarbons, aldehydes, ketones, esters).
- Indoor activities: cooking, tobacco smoking, use of water and solvents (amines, aliphatic and aromatic hydrocarbons, aldehydes, halocarbons).
- Ventilation systems: filters of heating, ventilation and air-conditioning systems (aliphatic and aromatic hydrocarbons, alcohols, halocarbons, aldehydes, ketones, terpenes, ethers, esters).
- Biological sources: humans, molds, bacteria, plants (terpenes, glycoesters; alcohols; esters; aldehydes).

Gran La Plata is located 50 km south-eastern of Buenos Aires City (Argentine) and has a population of 800,000 inhabitants (INDEC (National Institute of Statistic and Cense) 2011). This region can be divided into three areas, one industrial (I), one urban (U), and one residential (R), according to the characteristics of land use. This study shows the levels of indoor VOCs in different in homes ($n = 113$) and schools ($n = 43$) between the years 2007 and 2010, in the capital region of province of Buenos Aires, Argentina.

Complementarily, the lifetime cancer risk "LCR" is calculated to estimate the health impact of exposure to benzene, styrene, trichloroethylene, and tetrachloroethylene in children (Guo et al. 2004; Payne-Sturges et al. 2003; Yimrungruang et al. 2008; WHO 2009; Müller et al. 2009; Colman Lerner et al. 2012a, 2014).

Material and methods

Sampling and analytical methods

The organic vapor monitor 3M-3500 model uses a single charcoal sorbent and it is an efficient and simple device for collecting pollutants by diffusion (Begerow et al. 1999; Namieśnik et al. 2005; Kot-Wasik et al. 2007; Colman Lerner et al. 2014).

The methodology used consisted in placing passive monitoring (3M 3500) to monitor indoor VOCs at homes and schools of Gran La Plata in the three areas of study, industrial ($n = 53$), urban ($n = 62$), and residential ($n = 40$), following the methodology described by Colman Lerner et al. (2014). See Fig. 1.

The study comprised the analysis of 28 VOCs, which we can be classified into groups as follows: alkanes (hexane, heptane, octane, nonane, decane, undecane, dodecane, tridecane), cycloalkanes (methylcyclopentane, cyclohexane, methylcyclohexane), aromatic hydrocarbons (benzene, toluene, ethylbenzene, m+p-xylene, styrene, o-xylene, 4-ethyltoluene, 3-ethyltoluene, 2-ethyltoluene, naphthalene), chlorinated hydrocarbons (chlorbenzene, trichloroethylene, tetrachlorethylene), and terpenes (α-pinene, β-pinene, 3-carene, limonene). The analytical methodology used is described by Colman Lerner et al. (2014). In this last paper is carried out the analysis of outdoor VOCs in the same region and period of study. The 3 M passive sampler was extracted with 1.5 ml carbon disulfide containing internal standards (cyclododecane) and the 30-min extraction time (mechanical agitation) was followed by a quantitative VOC analysis using gas chromatography whit mass spectrometry (Agilent 7890-5977A SQ). The recovery coefficients were between 98 and 102% and the detection limits for the components were estimated as the threefold standard deviation (SD) of five replicate measurements of monitor blanks. Values between 0.01 and 0.05 μg m^{-3} were obtained for 30 days sampling.

Statistical analysis

The nonparametric test (Kruskal Wallis Test and Mann–Whitney U Test) was used for statistical analysis of results, according to the non-symmetrical distribution of the data (Sokal and Rohlf 1969; Zar 1998). Statistical analysis was

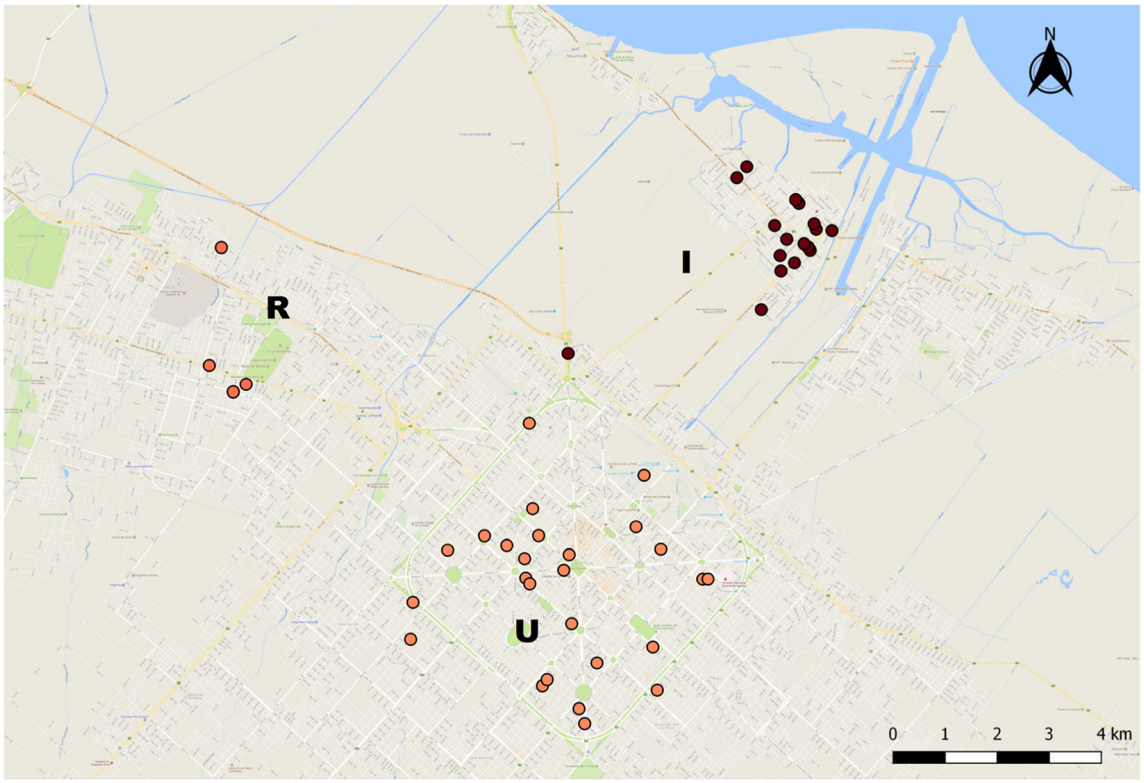

Fig. 1 Sampling points in Gran La Plata: urban (U), industrial (I) and residential (R) zones

prepared using InfoStat software. A p value below 0.05 was regarded to be statistically significant.

Cancer risk

Calculation of cancer risk requires the carcinogenic potency of the specific compound and the mean exposure of the target group. The lifetime cancer risk (LCR) associated to benzene, trichloroethylene, (group A, known carcinogens), styrene (IARC group 2B, possible carcinogen for human), and tetrachloroethylene (IARC group 2A, probable carcinogen for human) was calculated by multiplication of the chronic daily intake (CDI) by the IRIS system potency factor (IRIS—Integrated Risk Information System) for each target (IPCS 2000; Hoddinott and Lee 2000; Muller et al. 2003; Guo et al. 2004; Colman Lerner et al. 2014).

CDI in milligram per kilogram per day was calculated with the following equation:

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

where CC is the contaminant concentration (median in mg m^{-3}), IR the inhalation rate (0.417 $m^3\ h^{-1}$) (Castro 1998; Kalaiarasan et al. 2009), ED the exposure duration (hour per week), EF the exposure frequency (weeks per year), LE the length of exposure (9 years), BW the body weight (38 kg), and ATL the average lifetime (period over which exposure is averaged. ATL = 70 years were used in this work; NY is the number of days per year (365 days for homes and 308 days for schools). For the calculation of ED was estimated that children spend 10 h a day at home and 8 h daily in schools.

LCR was calculated for the exposure to benzene, styrene, trichloroethylene, and tetrachloroethylene in indoor air of homes and schools. The absorption factor of the VOCs for human was supposed to be 90% (Colman Lerner et al. 2014). For the calculations, the median concentrations of contaminants were exerted and according to USEPA (1998) the potency factor used was 0.029, 0.00057, 0.40, and 0.013 mg $kg^{-1}\ day^{-1}$, for benzene, styrene, trichloroethylene, and tetrachloroethylene, respectively.

Then the cumulative risk was calculated by summation LCR for the chemical j in each indoor environment i (Zhou 2011; Colman Lerner et al. 2014):

$$\mathrm{CR}i = \sum_j \mathrm{LCR}ij$$

The response addition approach has been recommended for the assessment of risk from mixtures of carcinogenic chemicals (NRC 1989; USEPA 2000; ATSDR 2004).

Finally, in order to estimate the total risk to which children are exposed, two ways of calculating it are proposed, taking into account indoor and outdoor exposure:

1. Adding the values of CR obtained by expositions in homes and schools, and the CR value obtained using the data of Colman Lerner et al. (2014) on in the same region of study in the same period of time.

$$CR_{indoorA} = LCR_{home} + LCR_{school}$$

$$CR_{totalA} = CR_{indoorA} + CR_{outdoor}$$

2. Adding the values of CR obtained by expositions in homes and schools, and the CR value obtained using the data of Colman Lerner on (2014), proportionally to the time in which each child is exposed in each environment during the 24 h of the day: 10 h in the home plus 8 h in the school (indoor exposure) - 6 h in outdoor environment.

$$CR_{indoorB} = \frac{10}{18}LCR_{home} + \frac{8}{18}LCR_{school}$$

$$CR_{totalB} = \frac{18}{24}CRindoorB + \frac{6}{24}CR_{outdoor}$$

Therefore, the risk to which children are exposed can be expressed in a value between CR_{totalA} and CR_{totalB}.

The World Health Organization (WHO) considered as "acceptable" a LCR under the range between 1E-5 and 1E-6 whereas the USEPA recommended a LCR under 1E-6 (IPCS 2000; Colman Lerner et al. 2014).

Results and discussion

VOCs monitoring

VOC levels found in homes and schools are shown in Tables 1, 2, and 3. It is observed that the values for the majority of analyzed VOCs are higher in homes with respect to

Table 1 Indoor levels of VOCs in homes and schools in residential area (μg m^{-3})

Compound	Homes ($n = 34$)				Schools ($n = 6$)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
Hexane	5.438	10.448	2.133	49.307	3.726	5.638	3.236	15.826
Heptane	2.780	5.182	1.117	31.305	2.088	1.920	1.120	2.679
Octane	1.709	2.934	0.665	9.433	1.203	1.245	0.757	2.223
Nonane	4.189	11.595	0.776	72.655	3.166	6.281	0.876	16.146
Decane	8.324	16.194	1.119	147.273	6.304	5.896	1.843	9.393
Undecane	5.997	13.060	0.923	100.873	4.990	5.086	1.384	9.443
Dodecane	1.821	3.285	0.368	22.203	2.152	3.129	0.480	9.149
Tridecano	0.615	1.002	0.208	5.266	0.712	9.795	0.345	52.548
Methylcyclopentane	1.853	4.792	0.504	31.951	1.503	2.217	0.848	5.571
Cyclohexane	1.553	2.278	0.217	11.092	0.879	0.978	0.039	1.981
Methylcyclohexane	1.987	3.840	0.512	21.287	3.125	4.383	1.231	11.902
Benzene	3.864	4.573	1.055	15.988	2.320	2.257	1.811	2.517
Toluene	12.644	21.255	4.389	118.791	6.082	12.054	3.750	34.218
Ethylbenzene	2.175	6.567	0.774	46.597	1.264	1.443	0.603	2.719
m+p-Xylene	6.176	26.081	1.763	223.741	4.569	5.237	1.042	11.014
Styrene	0.287	0.856	0.012	15.347	0.133	0.160	0.007	0.383
o-Xylene	2.128	6.983	0.874	50.093	1.468	1.710	0.704	3.604
4-Ethyltoluene	2.086	4.404	0.568	15.852	1.183	1.807	0.631	4.349
3-Ethyltoluene	0.816	1.699	0.194	6.653	0.362	0.633	0.282	1.464
2-Ethyltoluene	0.815	1.294	0.162	6.033	0.343	0.539	0.244	1.037
Naphthalene	0.515	4.202	0.072	45.316	0.591	6.574	0.091	36.836
Chlorbenzene	0.120	0.599	0.001	2.512	0.045	0.471	0.004	1.816
Trichloroetylene	0.053	0.610	0.002	9.741	0.050	0.059	0.017	0.141
Tetrachlorethylene	0.126	0.810	0.005	14.563	0.126	2.136	0.044	12.295
α-pineno	1.259	2.050	0.304	15.785	0.619	0.871	0.236	2.567
β-pineno	0.996	1.604	0.163	11.188	0.192	0.343	0.106	1.174
3-carene	0.013	0.040	0.005	0.192	0.002	0.002	0.001	0.008
limonene	16.492	23.694	1.712	135.764	1.976	3.047	1.157	5.979

Table 2 Indoor levels of VOCs in homes and schools in urban area (μg m^{-3})

Compound	Homes ($n = 48$)				Schools ($n = 14$)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
Hexane	5.988	7.853	1.997	28.775	5.420	6.770	3.218	28.990
Heptane	2.480	3.790	0.414	29.918	1.838	1.828	0.821	4.095
Octane	1.302	2.498	0.332	34.777	0.896	1.553	0.426	8.708
Nonane	3.766	9.642	0.580	71.142	4.356	45.182	0.672	354.435
Decane	7.223	20.887	0.912	233.879	3.386	29.523	0.762	255.314
Undecane	4.601	12.519	0.485	120.237	1.880	14.781	0.426	132.622
Dodecane	1.979	3.307	0.240	25.231	0.753	2.728	0.285	22.096
Tridecano	0.569	0.929	0.003	4.509	0.316	0.542	0.125	2.462
Methylcyclopentane	2.405	3.268	0.457	14.248	3.534	3.640	0.315	6.647
Cyclohexane	0.990	2.155	0.177	15.453	0.822	2.584	0.177	19.797
Methylcyclohexane	2.209	5.115	0.405	97.965	2.132	4.145	0.608	10.648
Benzene	3.039	3.685	0.704	20.595	1.483	2.507	0.958	9.066
Toluene	10.716	13.906	2.220	48.660	5.445	8.696	3.364	28.595
Ethylbenzene	1.466	1.755	0.399	4.045	1.146	1.625	0.347	5.715
m+p-Xylene	5.538	6.792	1.195	17.129	4.523	7.128	1.813	30.800
Styrene	0.175	0.216	0.015	0.902	0.068	0.161	0.047	0.544
o-Xylene	1.691	2.051	0.399	9.132	1.755	2.446	0.769	8.914
4-Ethyltoluene	1.522	3.052	0.392	48.376	1.950	5.334	0.627	36.750
3-Ethyltoluene	0.587	1.138	0.143	19.465	0.800	2.017	0.234	14.169
2-Ethyltoluene	0.413	0.936	0.095	14.036	0.364	1.582	0.144	11.360
Naphthalene	0.497	3.597	0.055	81.522	0.260	0.619	0.035	2.517
Chlorbenzene	0.713	0.824	0.001	3.184	0.945	1.260	0.000	3.061
Trichloroetylene	0.044	0.192	0.001	3.297	0.070	0.112	0.024	0.711
Tetrachlorethylene	0.112	0.469	0.007	5.893	0.785	2.792	0.017	15.511
α-pineno	0.738	1.019	0.145	4.722	0.314	0.787	0.067	4.274
β-pineno	0.545	0.832	0.057	4.565	0.079	0.174	0.012	0.783
3-carene	0.011	0.042	0.008	0.287	0.014	0.010	0.007	0.021
limonene	15.188	18.189	0.441	101.758	1.188	1.781	0.184	8.182

schools, in the three zones. Particularly, benzene, styrene, and tetrachlorethylene are with higher values in households with respect to schools, in all three areas.

Significant differences was obtained in 16 of the 28 VOCs analyzed (hexane, heptane, octane, tridecane, methylcyclopentane, cyclohexane, methylcyclohexane, bencene, ethylbencene, styrene, o-xylene, chlorbencene, α-pinene, β-pinene, and 3-carene) when the Kruskal Wallis is performing on the three zones with all of samples (schools and homes). On the other hand, significant differences in 11 of the 28 VOCs analyzed between I and U area (hexane, heptane, octane, tridecane, methylcyclopentane, cyclohexane, methylcyclohexane, bencene, ethylbencene, o-xylene, and tetrachlorethylene), 14 between I and R area (hexane, heptane, octane, methylcyclopentane, cyclohexane, methylcyclohexane, bencene, styrene, naphthalene, chlorbencene, α-pinene, β-pinene, 3-carene, and limonene), and 7 between U and R (octane, ethylbencene, styrene, 2ethyltoluene, α-pinene, β-pinene, and 3-carene) are obtained.

If we compare the medians of the different groups of VOCs, alkanes, cycloalkanes, chlorinated compounds, aromatic compounds, and terpenes, different profiles present homes and schools (Fig. 2), obtaining only significant differences for alkanes and cycloalkanes between the study areas.

Table 4 shows values from the literature for some indoor VOCs in different environments, such as homes, schools, offices, bookstores, and restaurants, finding similar levels to those found in this study, including benzene, styrene, and tetrachlorethylene.

Indoor/outdoor ratios (I/O) are shown in Table 5, using the indoor values of this study and the outdoor values published by Colman Lerner et al. (2014), with the same methodology of analysis in the same region and period of study. All of areas show ratios between 1 and 15, except chlorobenzene and 3-

Table 3 Indoor levels of VOCs in homes and schools in industrial area (μg m^{-3})

Compound	Homes ($n = 31$)				Schools ($n = 22$)			
	Median	Mean	Min	Max	Median	Mean	Min	Max
Hexane	21.437	25.084	5.492	73.358	8.410	13.262	3.114	61.369
Heptane	8.121	9.590	1.395	31.493	4.075	8.091	1.444	29.390
Octane	5.083	5.458	0.565	16.842	1.691	3.948	0.914	12.403
Nonane	6.588	10.513	1.484	45.155	4.445	11.631	1.038	104.517
Decane	8.922	14.964	1.672	64.424	3.421	10.855	1.231	56.322
Undecane	6.285	19.394	0.827	120.657	2.140	6.873	0.864	41.325
Dodecane	3.140	7.070	0.215	47.450	1.445	3.592	0.208	18.894
Tridecano	0.640	2.453	0.067	27.662	0.616	2.083	0.047	11.824
Methylcyclopentane	5.828	6.554	1.633	23.153	4.425	4.933	1.264	13.869
Cyclohexane	2.846	4.176	0.652	24.870	1.550	7.077	0.537	97.080
Methylcyclohexane	5.566	7.249	0.814	20.776	7.711	9.248	2.026	24.183
Benzene	12.837	13.322	1.166	37.462	2.454	5.313	1.140	22.987
Toluene	18.641	30.080	3.293	224.447	7.357	9.965	3.299	25.315
Ethylbenzene	2.739	4.856	0.476	22.084	1.354	1.822	0.666	3.970
m + p-Xylene	7.595	16.996	1.825	94.776	5.199	7.650	2.665	22.699
Styrene	0.236	0.305	0.064	1.360	0.120	0.127	0.016	0.241
o-Xylene	4.423	6.182	0.642	26.277	1.895	2.671	0.869	7.599
4-Ethyltoluene	2.206	6.162	0.592	79.843	1.284	1.815	0.704	5.981
3-Ethyltoluene	0.845	2.355	0.224	33.317	0.500	0.692	0.188	2.224
2-Ethyltoluene	0.713	1.724	0.133	20.815	0.318	0.540	0.172	1.750
Naphthalene	0.412	1.173	0.018	10.995	0.190	0.642	0.006	4.138
Chlorbenzene	0.299	0.751	0.009	2.936	0.946	1.134	0.010	2.989
Trichloroetylene	0.039	0.077	0.001	0.721	0.065	0.065	0.008	0.200
Tetrachlorethylene	0.042	0.118	0.008	1.030	0.144	0.227	0.008	1.283
α-pineno	0.716	2.181	0.110	28.230	0.235	0.578	0.055	2.830
β-pineno	0.514	1.244	0.051	9.531	0.080	0.182	0.010	0.767
3-carene	0.013	0.023	0.003	0.143	0.009	0.039	0.004	0.165
limonene	13.552	19.401	1.550	90.239	2.521	3.717	0.220	11.181

carene which have values less than 1. Ratios equal to 1 ± 0.5 indicate compounds that arise primarily from outdoor sources (like chlorinated compounds), ratios between 1.5 to 10 indicate both indoor and outdoor sources, as the majority of COVs studied in this work, and ratios greater than10 reveal primarily or exclusively indoor sources (Jia et al. 2008), like β-pinene, limonene, decane, and undecane.

The study region has a petrochemical complex which is one of the most important in South America. The prevailing winds here are from N, NE, and E (Ratto et al. 2010; Ratto et al. 2012). In that sense, the levels of VOCs found in indoor environments and the ratios calculated show the influence of the petrochemical industry and the influence of mobile sources in the residential and urban areas (Massolo et al. 2010; Wichmann et al. 2009; Colman Lerner et al. 2014). In this studies found that the concentrations of indoor VOCs were generally higher than those of outdoor VOCs, with minor seasonal variations and without statistical significance. Massolo et al. (2010) found indoor/outdoor ratios of concentration values between 1 to 5 for aromatics and terpenes. As principal groups, the outdoor level of alkanes was dominated by C6–C8 alkanes (hexane, heptane, and octane), whereas decane, undecane, dodecano, and tridecane are characteristic of indoor environments with I/O values from 1.7 to 13.5. Colman Lerner et al. (2014) collect and compare the values of VOCs, indoor and outdoor and for the same areas, found for two different periods, the first corresponding to a period of monitoring between 2000 and 2002, and the second between 2007 and 2010. It is observed that, on the one hand, the values of VOCs decrease markedly in the second period, compared with the first, mainly in the industrial zone. But also that the higher values of indoor VOCs are maintained, so that the I/O coefficients are generally greater than one, and also higher than those found in the first one.

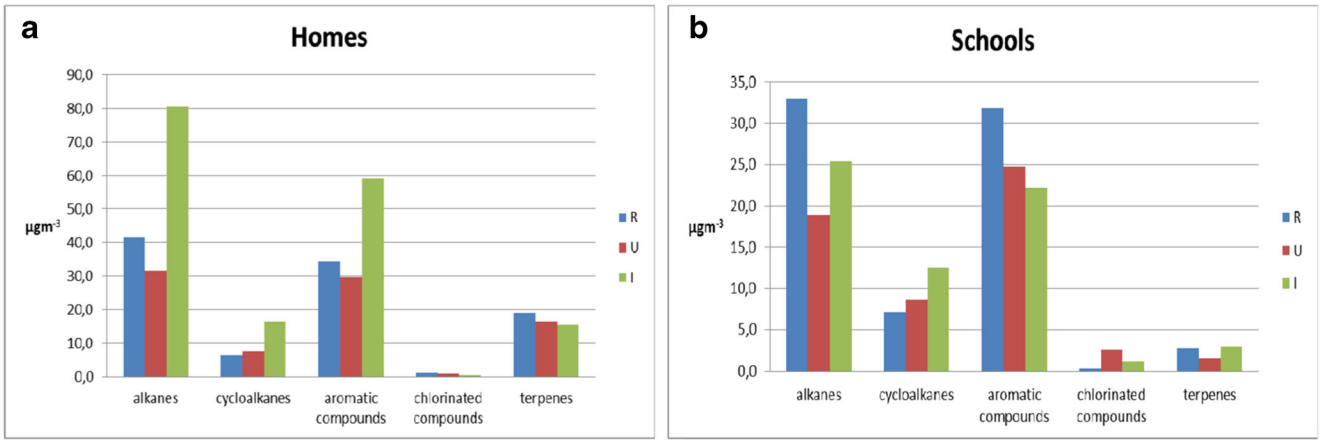

Fig. 2 Profile of families of compounds in homes and schools in La Plata and surrounding areas (median in µg m^{-3}). **a** Homes. **b** Schools

Cancer risk

Although cumulative cancer assessment can involve a very large number of potential combinations of chemicals and interactions inherent to the environmental setting, USEPA and WHO/IPCS recommends the response addition model for independent action for cancer risk. Use of the IRIS values for slope factor or unit risk result in plausible upper bounds to the lifetime excess cancer risk of the components. It has been raised with concern that summing upper bound risks may lead to unreasonably high estimates of the mixture risk, but also its observed that the error in the simple sum of the upper

Table 4 Indoor levels of VOCs in different environments (µg m^{-3})

Compound	Home[1–4]	School[2]	Bookstore[4]	Office[1–3]	Restaurant[2–3]	Home[5]
Hexane	NR	NR	NR	NR	NR	3.1–8.0
Decane	NR	NR	NR	NR	NR	4.1–8.0
Dodecane	NR	NR	NR	NR	NR	1.2–3.4
Cyclohexane	NR	NR	NR	NR	NR	0.6–1.3
Methylcyclohexane	NR	NR	NR	NR	NR	NR
Benzene	0.7–13.9	0.6–3.0	17.1	0.5–5.9	1.1–22.7	1.9–2.2
Toluene	7.5–38.4	4.4	27.0	1.5–22.0	57.0	5.5–7.0
Ethylbenzene	1.3–2.3	NR	NR	0.3–2.4	6.2	1.3–1.4
m+p-Xylene	3.9	2.7	17.3	0.5–7.7	21.9	4.5–5.0
Ethylbenzene+mXylene	NR	NR	NR	NR	NR	NR
o-Xylene	0.5–1.9	0.9	NR	0.07	NR	1.3–1.7
p-Xylene	NR	NR	NR	NR	NR	NR
Styrene	0.1–4.0	0.1	NR	0.08	0.3–6.0	0.1–0.2
Naphthalene	0.8–15.1	NR	NR	1.7	0.9	0.2–2.0
Trichloroetylene	0.3	NR	NR	NR	0.2	NR
Tetrachlorethylene	0.3	1.3	NR	NR	0.4	0.1
α-pineno	11.9	0.03	NR	NR	NR	0.5–1.0
β-pineno	NR	NR	NR	NR	NR	NR
3-carene	NR	NR	NR	NR	NR	NR
limonene	20.1	NR	NR	NR	NR	4.2–10.2

NR not reported

[1] Zhou 2011

[2] Guo et al. 2004

[3] Min Kin 2001

[4] Sarigiannis 2011

[5] Colman Lerner et al. 2014

Table 5 Indoor/outdoor ratio (I/O)

Compound	Industrial I/O ratio	Urban I/O ratio	Residential I/O ratio
Hexane	3.3	1.6	1.9
Heptane	2.2	1.7	2.5
Octane	3.1	1.5	3.1
Nonane	2.9	4.1	7.2
Decane	4.0	5.2	11.9
Undecane	4.8	5.6	13.6
Dodecane	2.4	3.4	5.5
Tridecano	2.4	2.1	5.4
Methylcyclopentane	3.1	2.0	2.0
Cyclohexane	3.1	2.8	6.8
Methylcyclohexane	3.5	2.9	4.0
Benzene	1.7	1.5	1.7
Toluene	2.5	1.5	1.8
Ethylbenzene	2.2	1.3	1.7
m+p-Xylene	2.0	1.3	1.1
Styrene	3.7	2.5	3.3
o-Xylene	2.8	1.4	1.6
4-Ethyltoluene	2.3	1.6	1.8
3-Ethyltoluene	2.4	1.6	1.7
2-Ethyltoluene	2.8	1.5	1.9
Naphthalene	4.2	3.2	3.6
Chlorbenzene	0.8	1.0	0.1
Trichloroetylene	1.3	1.4	1.2
Tetrachlorethylene	2.6	2.1	1.5
α-pineno	4.3	4.2	6.3
β-pineno	10.7	11.2	14.4
3-carene	0.2	0.3	0.2
limonene	18.8	13.8	17.3

bound risks is small relative to other uncertainties, concluding that the sum of the upper bound risks provides useful information regarding the overall risk from mixtures of carcinogens (USEPA 2000; ATSDR 2004; Meek et al. 2011).

Respect to the obtained results, as shown in Table 6, only the LCR value for benzene exceeds the requirements of the US EPA (1 E-6), both in homes as schools of I and R areas. A similar situation occurs in U and R area. According to WHO, the values of LCR for benzene, styrene, trichloroethylene, and tetrachlorethylene in homes and schools are acceptable (under the range between 1E-5 and 1E-6). When calculating cumulative risk for indoor environments ($CR_{indoorA}$ and $CR_{indoorB}$), the life time cancer risk (for children) does not meet the requirements of the US EPA, but does meet the requirements of the WHO, in the three study areas. Taking into account the exposure in the outdoor environments ($CR_{outdoor}$), the risk values do not change substantially, since the $CR_{outdoor}$ is an order of magnitude smaller than the cumulative risk indoor (CR_{indoor}) accumulated indoor risk, obtaining total accumulated risk (CR_{totalA} and CR_{totalB}) values not acceptable to the US EPA, but acceptable to WHO.

Conclusions

The VOC levels were higher in homes than in schools regardless of the subarea (residential, urban, or industrial) analyzed, this being due possibly to frequently use of cleaning products, home renovations, like painting of rooms and furniture, etc.

The influence of nearby industry (due to prevailing wind directions) is evident in all areas, mainly in the industrial area due to high levels of VOCs emissions from industrial sources (n-hexane, n-Heptane, cycloalkanes, etc.). Similarly, the influence of emissions from mobile sources in urban and residential areas is manifested in the results. However, the levels of

Table 6 Life time cancer risk (LCR) and cumulative risk (CR) for children exposure in indoors environments (homes and schools) for benzene (B), styrene (S), tetrachloroethylene (TE), and trichloroethylene (TRI)

	Industrial				Urban				Residential			
	B	S	TE	TRI	B	S	TE	TRI	B	S	TE	TRI
LCR_{home}	4.84E-06	1.75E-09	7.09E-09	2.02E-07	1.14E-06	1.30E-09	1.89E-08	2.28E-07	1.46E-06	2.12E-09	2.13E-08	2.75E-07
LCR_{school}	1.10E-06	1.05E-09	8.40E-09	3.38E-07	6.62E-07	5.97E-10	1.57E-07	3.64E-07	1.04E-06	1.17E-09	2.52E-08	2.60E-07
CR_{home}	5.05E-06				1.39E-06				1.75E-06			
CR_{school}	1.44E-06				1.18E-06				1.32E-06			
$CR_{indoor(A)}$	6.49E-06				2.57E-06				3.07E-06			
$CR_{indoor(B)}$	3.45E-06				1.30E-06				1.56E-06			
$CR_{outdoor}$	4.80E-07				4.40E-07				3.80E-07			
$CR_{total(A)}$	6.97E-06				3.01E-06				3.45E-06			
$CR_{total(B)}$	2.70E-06				1.08E-06				1.26E-06			

VOCs found are within the ranges reported in the literature for similar indoor environments.

LCR values for benzene, styene, and tetrachlorethylene do not exceed the limits established by WHO. However, the LCR value for benzene exceeds the limits suggested by the US EPA.

Finally, the cumulative total risk (CR_{total}) calculated does not change substantially, taking into account external levels of benzene, styrene, and tetrachlorethylene. In this sense, the external risk is smaller by an order of magnitude than the internal risk, regardless of how it is calculated (CR_{totalA} or CR_{totalB}).

Acknowledgements The authors gratefully acknowledge the support of the Scientific and Technical Research Council (CONICET), of the Commission for Scientific Research of the Buenos Aires Province (CIC-PBA) and the National University of La Plata (UNLP).

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