

# Health risk represented by inhaling polycyclic aromatic hydrocarbons (PAH) during daily commuting involving using a high traffic flow route in Bogota

Exposición a hidrocarburos aromáticos policíclicos durante desplazamientos diarios en una vía de alto flujo vehicular en Bogotá

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Received 18<sup>th</sup> March 2012/Sent for Modification 22<sup>th</sup> April 2012/Accepted 12<sup>th</sup> September 2012

## ABSTRACT

**Objective** Assessing the risk to health by inhaling particles and particle-bound PAH during daily commuting along a high traffic flow route/corridor in Bogota.

**Methods** A van was equipped with a PAS2000 photo-electric sensor for real-time measurement of particle-bound PAH and a DustTrak for monitoring PM<sub>10</sub> concentration; it drove along typical commuting routes in the city. Exposure to particles and particle-bound PAH was assessed by using an inhalation intake model.

**Results** A similar trend was observed for both PM<sub>10</sub> and PAH concentration, indicating that traffic was the same source for both contaminants. Extreme PM<sub>10</sub> and PAH inhalation concentrations were recorded every time direct bus and microbus emissions were measured by the van. Inhalation model results indicated that exposure was significantly greater when using avenues having mixed traffic use (i.e. buses, minibuses, passenger vehicles, motorcycles) compared to using roads where the TransMilenio system (articulated buses) had been implemented.

**Conclusions** The results may support evaluating bus drivers, commuters and bike users' exposure to toxic compounds in the city.

**KeyWords:** Air pollutant, airborne particulate matter, inhalation exposure, PAH. (source: MeSH, NLM).

## RESUMEN

**Objetivo** El presente estudio buscó estimar la exposición a material particulado e Hidrocarburos Aromáticos Poli cíclicos (HAP) asociados a partículas durante el desplazamiento diario de la población en una vía de alto flujo vehicular en Bogotá.

**Método** Se instaló un equipo "dust-track" para la medición de partículas y un equipo fotoeléctrico "PAS2000" para la medición de los HAP, ambos en un vehículo

tipo van que replicó el desplazamiento diario de personas de la casa al trabajo y viceversa. Con el fin de valorar la exposición personal a estos contaminantes según el tipo de vía se usó un modelo de inhalación.

**Resultados** Se observó una tendencia similar entre la concentración del material particulado menor a 10 micrómetros ( $PM_{10}$ ) y los HAP, indicando que ambos provienen del tráfico principalmente. El modelo de inhalación mostró que las concentraciones a las que está expuesta una persona son mayores en vías con diferentes tipologías de vehículos (carros, buses y busetas, camiones, motocicletas) que en vías de uso exclusivo público para el sistema TransMilenio.

**Conclusiones** Los resultados de este estudio son útiles en la evaluación de la población a contaminantes tóxicos del aire y pueden ser utilizados para apoyar políticas públicas destinadas al mejoramiento de la calidad del aire.

**Palabras Clave:** Material particulado, hidrocarburos policíclicos aromáticos, exposición a riesgos ambientales (*fuentes: DeCS, BIREME*).

**A**ir pollution poses risks to human health, the environment and the quality of life. Air pollution-related epidemiological studies have shown that ambient ozone and fine particulate matter are closely associated with a wide range of adverse human health outcomes. The two air pollutants of greatest concern are ozone and  $PM_{2.5}$  (particulate matter with an aerodynamic diameter less than 2.5  $\mu$ m) due to their adverse human health effects. Studies have demonstrated that  $PM_{2.5}$  leads to premature death, an increased risk of heart attack, adverse effects on lung function and other adverse health effects (1-5).  $PM_{2.5}$  consists of hundreds of compounds (carbonaceous species, metals, inorganic ions, polycyclic aromatic hydrocarbons-PAHs) and originates from several sources (i.e. vehicles, industry, fugitive dust and erosion).

PAHs have been recognized as carcinogenic compounds which are found in the particulate matter in the atmosphere (6-7). PAHs are mainly emitted as incomplete combustion products. PAHs' diurnal profiles correspond to traffic conditions, which is why PAHs have been suggested as tracers of vehicle activity (8-10).

Bogotá is Colombia's main financial and political centre; Bogotá has experienced rapid population growth and increased economic activity during the last few years. The rapid bus transport system (known as TransMilenio) which began in 2001 has changed the city's form and it is a mass transportation model for other cities in the country and around the world. Unfortunately, environmental protection has not advanced at the same rate as economic

growth. Bogotá is recognized as one of the cities having the worst air quality conditions in Latin-America. Uncontrolled emissions to the atmosphere from mobile and point sources are the main cause of deterioration in air quality.

Air pollutants are continuously monitored by Bogotá's Air Quality Monitoring Network consisting of 15 stations distributed throughout the city. Annual average  $PM_{10}$  concentration during the last decade (2002-2012) has been in the 52-79  $g/m^3$  range, this being above the 20  $g/m^3$  standard recommended as being safe for public health by the World Health Organization (20  $g/m^3$ ). Epidemiological studies during the same period observed a strong association between air pollution and respiratory disease, especially in children from low-income sections of the population (11-13).

This collaborative work involving the Universidad de La Salle in Colombia and the University of Tokyo in Japan was aimed at investigating the risk to health by inhaling particles and particle-bound PAHs during daily commuting in Bogota. This is the first work (to the best of our knowledge) involving a mobile campaign in Bogota for evaluating exposure to  $PM_{10}$  and PAHs using a van equipped with air quality monitoring instruments, driving along main corridors in the city. The results can support evaluating bus drivers, commuters and bike users' exposure to toxic compounds in the city.

## METHODS

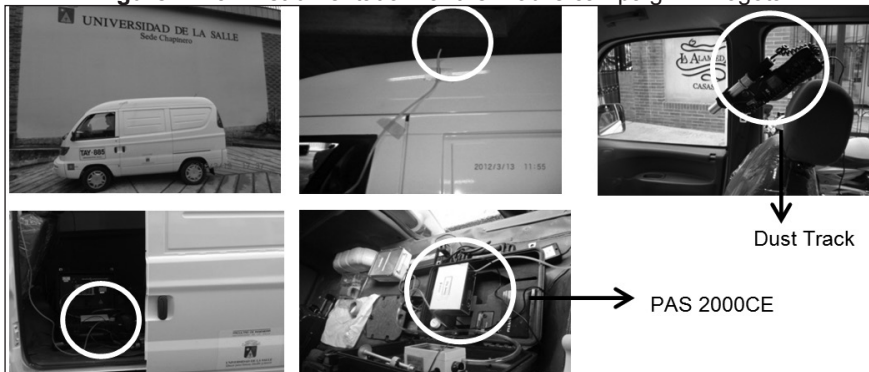
A mobile field campaign was conducted in Bogota, Colombia (74°4'33''W 4°35'53'' N) over a three-day period (two weekdays-13/03/2012 and 16/03/2012-and one holiday-19/03/2012) for estimating particulate matter concentration of less than 10 micrometres ( $PM_{10}$ ) and polycyclic aromatic hydrocarbons (PAHs) during morning and evening commuting in the city.

A photoelectric aerosol sensor (PAS 2000CE) was used for measuring particle-bound PAHs in ambient air every minute. The PAS is a portable instrument (68mm x 175mm x 124mm) weighing less than 3 pounds (the instrument user's guide gives a complete description of the analytical technique and operating instructions - 14). Briefly, a PAS sensor uses a UV lamp for photo-ionisation of particles bound with PAHs. Specific PAS UV-lamp irradiation energy and wavelength guarantee that only particles with adsorbed PAH will emit photoelectrons and not other aerosols (dust, tirewear, salt). Several studies have found a good correlation between the aerosol photoemission signal and total PAH concentrations analyzed by gas

chromatography on PM filter samples (14-15). The PAS monitor signal in amperes (A) can be translated into ng/m3.

A dust-track instrument (Microdust PRO Casella) was used for estimating PM<sub>10</sub> concentration; it can sample PM<sub>2.5</sub> and PM<sub>10</sub> ranging from 0.001 to 2500 mg/m3 every minute using infrared light scattering. The 880 nm infrared beam wavelength is projected through the sample where particle contact causes the light beam to disperse; calibration thus uses a zero (zero air) and cell functioning as an optical filter for calibration at 0.1mg/m3.

**Figure 1.** Van instrumentation for the mobile campaign in Bogota



The PAS and Casella instruments were set up in a school van (Hafei model 2012) to replicate daily commuting from and to Bogota’s downtown. Power was supplied from the van’s battery using a power inverter (Techman 800 W). A hose connected to the PAS instrument was placed on the van’s roof to capture ambient air samples. The dust-track sampler was stuck to the passenger-sidewindow and kept partially open during the study (Figure 1).

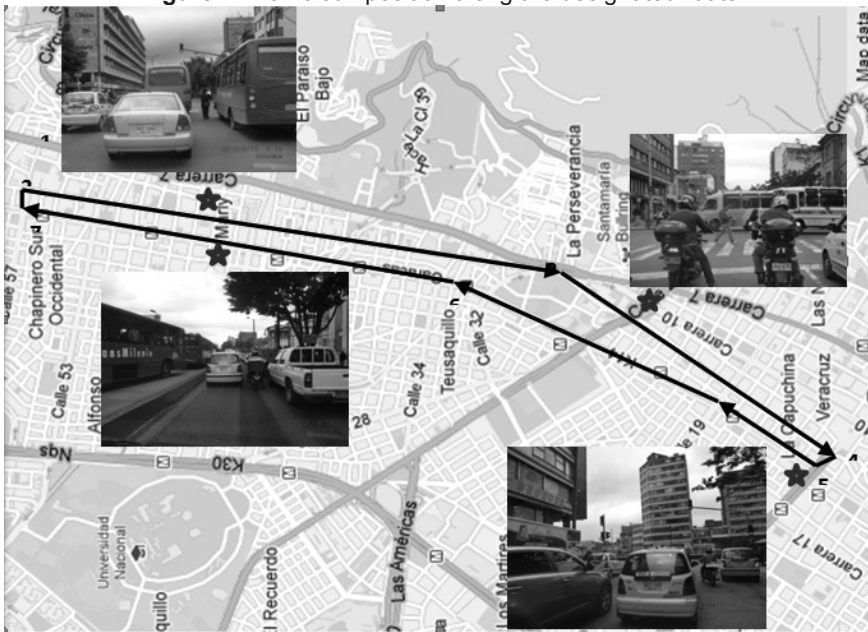
**Table 1.** Routes in Bogota’s central area used to replicate daily commuting

Station points	Route description
1	Universidad de La Salle in Chapinero (Carrera 5 Calle 59)
2	Calle 59 from Carrera 7 to Carrera 13
3	Carrera 13 from Calle 59 to Calle 13
4	Calle 13 from Carrera 13 to Avenida Caracas
5	Avenida Caracas from Calle 13 to Calle 53
6	Calle 53 from Avenida Caracas to Carrera 7
7	Carrera 7 from Calle 53 to Calle 59
8	Universidad de La Salle in Chapinero (Carrera 5 Calle 59)

The campaign during the study period was designed to replicate morning, midday and evening commuting along congested roads in Bogota. The route covered roads in Bogota’s central areas, Chapinero and down town which are known to have large-scale commercial activity and heavy traffic flow (Table 1).

Traffic composition depended on the route driven. From Chapinero (point 1) to downtown (point 4) the ride was along Carrera 13 where a mixture of traffic was found: buses and minibuses (diesel operated), passenger gasoline vehicles, taxis (gasoline or natural gas) and motorcycles. From downtown (point 4) to Chapinero (point 7) the ride was along Avenida Caracas where the rapid bustransit system (TransMilenio) operates in exclusive lanes (diesel fuel-powered buses). There is a mixture of passenger cars, taxis and motorcycles alongside the BRT lanes (Figure 2).

**Figure 2.** Traffic composition along the designated route



### Health risk estimate

Exposure was assessed to estimate the risk to health of inhaling particles and particle-bound PAHs in which pollutant concentration, the duration of exposure and characteristics of exposed people were considered. The proposed model involved the following (16):

$$I_a = \frac{C_a * IR_a * t_{Ea} * f_E * ED}{BW * T_{ave}}$$

where  $I_a$  = inhalation intake (mg/kg/day)

$C_a$  = pollutant concentration in air (mg/m<sup>3</sup>)

$IR_a$  = inhalation rate (30 m<sup>3</sup>/day for a normal adult)

$t_{Ea}$  = duration of exposure (h/day)  
 $f_E$  = exposure frequency (days/year)  
 ED = exposure duration (years)  
 BW = body weight (kg)  
 $T_{ave}$  = average exposure period (in days)

## RESULTS

Morning, midday and evening commuting was simulated during the three days of the survey (Table 2).

**Table 2.** Description of daily commuting during the study period

Day	Commuting	Starting time	Finishing time
March 13, 2012 (Tuesday)	Morning	8.34am	9.40am
	Midday	11.51am	12.56pm
	Evening	5.06pm	5.50pm
March 16, 2012 (Fri- day)	Morning	8.45am	9.36am
	Midday	12pm	1pm
	Evening	5pm	5.59pm
March 19, 2012 (Mon- day - holiday)	Morning	8.57am	9.25am
	Midday	11.54am	12.34pm
	Evening	5.01pm	5.34pm

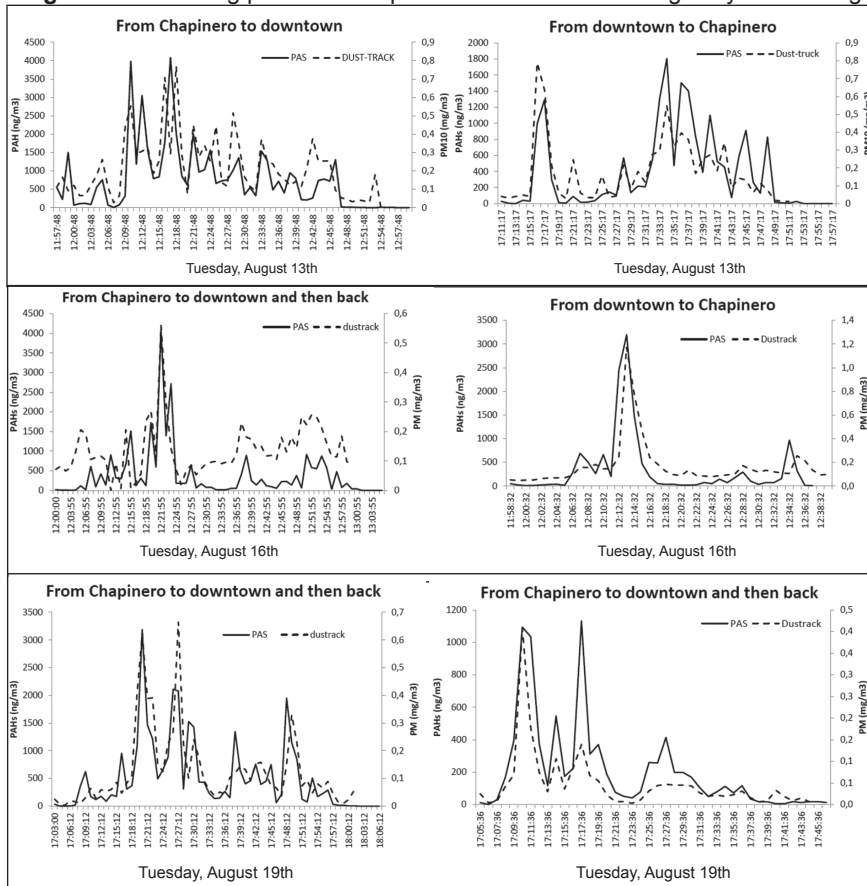
Particle and particle-bound PAH monitoring during morning commuting was not properly recorded due to technical difficulties; the results, therefore, included only midday and evening commuting during these days. A similar trend for PAS and dust-track recordings was observed regarding all daily commuting, probably indicating a similar source for particles and particle-bound PAHs.

Typical PAH and  $PM_{10}$  concentrations during the holiday (March 19) were  $<500$  ng/m<sup>3</sup> and  $<0.2$  mg/m<sup>3</sup>, respectively (Figures 3e, 3f). Extreme events were recorded when the van was invaded by bus or microbus exhaust; PAH concentration reached 3,000 ng/m<sup>3</sup> and  $PM_{10}$  1.2 mg/m<sup>3</sup> (at 12.14pm on March 19th). Exhaust emission resulted in 1,000 ng/m<sup>3</sup>.

PAH concentration and 0.4 mg/m<sup>3</sup>  $PM_{10}$  during evening commuting on the same day (at 5.10pm and 5.15pm on March 19th). Differences in extreme event concentration were due to different factors such as closeness to a vehicle emitting excessive exhaust, exhaust concentration, site characteristics (at 12.14pm the van was passing a road enclosed by buildings on Kra 13 & Cl 28 whereas at 5.10pm the van was on a road lacking the canyon effect on Kra

13 & CI 45) and meteorological conditions (it was raining for most of the day with periods of cloudiness and sun shine).

**Figure 3.** Monitoring particles and particle-bound PAHs during daily commuting



During the weekdays (March 13th, 16th) events involving extreme PAH and  $PM_{10}$  concentrations were very common (Figures 3a-3d). The chosen routes had heavy traffic flow and the van was constantly invaded by exhaust plumes from buses and minibuses. The largest PAH and  $PM_{10}$  concentrations were 4,000 ng/m<sup>3</sup> and 0.8 mg/m<sup>3</sup>, respectively, this being eight and four times higher than typical concentration during a holiday. Such large concentrations were recorded on March 13th at 12.10pm and 12.17pm when riding along Carrera 13 from CI 45 to CI 36, and on March 16th at 12.21pm riding over the same route on Carrera 13.



The ride from Chapinero to downtown on March 16th was made on Carrera 13 where a mixture of traffic was found (buses and microbuses, taxis, passenger vehicles, motorcycles) while the ride from downtown to Chapinero was made on Avenida Caracas along the BRT system. There was a significant decrease in particle and particle-bound PAH concentration when riding on Avenida Caracas (from 12.33-12.51pm and 5.38-5.53pm on March 16th) compared to Carrera 13 (Figures 3c, 3d).

### Health risk

Inhalation intake ( $I_a$ ) was estimated for each journey during the three sampling days; it was calculated for a bus driver working daily on the selected routes. A 30 m<sup>3</sup>/day inhalation rate, 240 days/year exposure frequency, 30 years exposure duration, a 70 kg body weight and an average time equal to exposure duration in days were considered for a normal adult. Exposure duration varied from day to day and was estimated as the time spent from the starting to the finishing point.

**Table 3.** Exposure (mg/kg/day) to PM<sub>10</sub> and PAHs during the study period

PM <sub>10</sub>	March 13 <sup>th</sup> , 2012		March 16 <sup>th</sup> , 2012		March 19 <sup>th</sup> , 2012	
$I_a$ (mg/kg/day)	midday	evening	midday	evening	midday	evening
<i>average</i>	2.59E-03	1.58E-03	1.62E-03	1.49E-03	1.98E-03	5.46E-04
<i>maximum</i>	9.04E-03	7.11E-03	6.58E-03	7.81E-03	1.38E-02	4.80E-03
<i>minimum</i>	3.17E-04	1.08E-04	5.87E-05	3.52E-05	5.28E-04	3.52E-05
PAHs	March 13 <sup>th</sup> , 2012		March 16 <sup>th</sup> , 2012		March 19 <sup>th</sup> , 2012	
$I_a$ (ng/kg/day)	midday	evening	midday	evening	midday	evening
<i>average</i>	9.52	3.86	4.91	6.52	3.91	2.46
<i>maximum</i>	47.86	16.26	48.14	37.47	37.51	13.30
<i>minimum</i>	0.06	0.05	0.06	0.01	0.07	0.01

Exposure to particles and particle-bound PAHs was greater during weekdays than weekends and during midday commuting than evening commuting (Table 3). This indicated that Bogota's traffic is permanently emitting toxic compounds to the atmosphere and exposure can have a great magnitude at any time of the day, and not just during rush-hours as was thought.

## DISCUSSION

The ratio of exposure to particle-bound PAHs when riding along Carrera 13 cf riding along Avenida Caracas (based on the survey conducted on March 16th) was approximately twice as great, indicating that bus drivers on Carrera 13 were exposed to higher levels of PAHs than BRT drivers on Avenida Caracas. A similar implication could be extended to people commuting along these two corridors. The ratio of exposure to PM<sub>10</sub> when riding along Carrera 13 cf



riding along Avenida Caracas was approximately one, indicating that exposure to  $PM_{10}$  was similar for both corridors.

Greater exposure to particle-bound PAHs along Carrera 13 was explained by constant emission from poorly maintained buses and minibuses having aggressive driving patterns. Slighter exposure on Avenida Caracas was explained by lower emissions from TransMilenio buses having an ongoing maintenance program and better driving patterns[JCG2].

This study has implications for bike users regarding this difference in exposure, since bike lanes are present on Carrera 13 but not on Avenida Caracas, obliging bike-riding commuters to ride along Carrera 13 having higher exposure to toxic compounds, as described above. These results may support the evaluation of bus drivers, commuters and bike users' exposure to toxic compounds in the city ■

**Acknowledgments:** This project was funded by the University of Tokyo's Center for Sustainable Urban Regeneration (cSUR) Global Center for Excellence Program (GCOE) and the School of Engineering at the Universidad de La Salle in Bogota.

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