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Spatial and temporal variations and mobile source emissions of polycyclic aromatic hydrocarbons in Quito, Ecuador

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Abstract

Motor vehicles are a major source of air pollution in Quito, Ecuador; however, little work has been done to characterize spatial and temporal variations in traffic-related pollutants, or to measure pollutants in vehicle emissions. We measured PAH continuously for one year at two residential sites in Quito, and PAH and traffic patterns for one week near a busy roadway. Morning rush-hour traffic and temperature inversions caused daily PAH maxima between 06:00 and 08:00. SO₂, NO_x, CO, and PM_{2.5} behaved similarly. At the residential sites PAH levels during inversions were 2–3-fold higher than during the afternoon, and 10–16-fold higher than 02:00–03:00 when levels were lowest. In contrast, at the near-roadway site, PAH concentrations were 3–6-fold higher than at the residential sites, and the effects of inversions were less pronounced. Cars and buses accounted for >95% of PAH at the near-roadway site. Near-roadway PAH concentrations were comparable to other polluted cities.

Keywords

Air pollution; PAH; Spatial and temporal variation; Atmospheric inversions; Vehicular exhaust emissions; Quito, Ecuador

1. Introduction

Polycyclic aromatic hydrocarbons (PAH), many of which are mutagenic and carcinogenic, are present at high levels in particulate matter in vehicle exhaust emissions (IARC, 1983; Rogge et al., 1993; Miguel et al., 1998; Nielsen, 1996). PAH emission rates from vehicles vary significantly depending on fuel and vehicle type, engine load, and use of pollution control equipment such as catalytic converters. Rogge et al. (1993) found that gasoline-powered

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Atmospheric temperature inversions and proximity to roadways strongly influence potential human exposure to ambient airborne PAH in Quito, Ecuador.

automobiles without catalytic converters emit >20-fold higher PAH levels than cars equipped with catalytic converters, and up to 7-fold higher PAH levels than new heavy-duty diesel trucks. Jensen and Hites (1983) demonstrated that the concentrations of alkylated and oxygenated PAH species in diesel exhaust particles significantly decreased as cylinder exhaust temperatures increased reflecting changes in engine load. Westerholm and Li (1994) reported that PAH levels in diesel combustion emissions were directly related to PAH levels in uncombusted fuels. Once emitted into the atmosphere, PAH in particles may undergo transformation by photooxidation (Molina et al., 2004; Esteve et al., 2006). As a result, the relative abundance of individual PAH in particles collected far from sources of vehicle exhaust may be quite different compared to fresh tailpipe emissions.

In Quito, Ecuador, a city of ~1.5 million people in the Andes Mountains, emissions from vehicles are a significant cause of air quality problems (Corpaire, 2006a). Air quality has generally worsened in Quito since the 1970s as the number of vehicles has steadily increased, with many vehicles lacking pollution control technology (Corpaire, 2006a; INEC, 2005). During the last census (2003), only 45% of gasoline-powered vehicles registered in Quito were equipped with catalytic converters (Corpaire, 2006a). Vehicular emissions contribute both gaseous and particulate emissions that can affect health. Children in Quito who are exposed to high levels of carbon monoxide have elevated blood carboxyhemoglobin levels and are at greater risk of experiencing acute respiratory infections (Estrella et al., 2005). Also, for the past three years (2004–2006) the annual average concentrations of particulate matter with an aerodynamic diameter of $\leq 2.5 \mu\text{m}$ ($\text{PM}_{2.5}$) in Quito have been 25–38% higher than the air quality standard ($15 \mu\text{g}/\text{m}^3$) (Corpaire, 2006b).

Another factor that may contribute to air quality problems in Quito is geography. Quito is located ~2800 m above sea level and just south of the equator ($0^\circ 5'S$) in a valley flanked to the east and west by volcanoes that rise >2000 m above the valley floor. As a result, Quito regularly experiences atmospheric temperature inversions. Inversions can impair air quality by impeding vertical mixing of air masses. Research in other cities – e.g., Mexico City, Los Angeles, and Göteborg (Sweden) – has shown that inversions can lead to significant, short-term buildup of air pollutants (Chow et al., 2002; Janhäll et al., 2006; Reisen and Arey, 2005).

To date no studies have been performed in Quito to characterize spatial and temporal variations in PAH levels in ambient air, or to measure PAH in emissions from vehicles. We addressed these data gaps by measuring ambient PAH concentrations continuously for 1 y (March 2004–February 2005) at two monitoring stations, and measuring street-level PAH and traffic patterns at a third location during July 2004. We also continuously measured SO_2 , NO_x , and CO at both monitoring stations and $\text{PM}_{2.5}$ at one of the stations. Effort was made to determine the effects of atmospheric inversions on the levels of these pollutants. PAH measurements were made using photoelectric aerosol sensors (PAS), an alternative to standard filtration-based methods for analyzing particle-bound PAH (Hart et al., 1993; Burtscher, 1992; McDow et al., 1990; Niessner et al., 1990). PAS have been used to measure PAH levels in source emissions, including oil burner and automobile exhaust emissions, as well as in ambient air (McDow et al., 1990; Agnesod et al., 1996; Ramamurthi and Chuang, 1997; Dunbar et al., 2001; Marr et al., 2004). PAS measure PAH continuously at intervals as short as < 1-min., which made them ideal for use in Quito.

2. Material and methods

2.1. Study sites

Ambient PAH monitoring was done from March 4, 2004 to February 28, 2005 at two monitoring stations operated by the Red Metropolitana de Monitoreo Atmosférico de Quito

(Fig. 1). One station (El Condado) is located ~20 m from the southbound lanes of a four-lane roadway (two in each direction) in the northern outskirts of Quito. The grade of the road at the monitoring site was ~ 5–10%. The second site (El Camal) is located on the roof of a 3-story hospital in a residential area of central Quito.

Monitoring of near-roadway PAH levels was done from 06:30 to 18:30 on three consecutive weekdays (Tuesday, July 6–Thursday, July 8, 2004) and one weekend day (Saturday, July 10, 2004). Monitoring was done on the east side of the northbound lanes of Avenida 12 de Octubre, a six-lane avenue that runs along the west side of the Pontificia Universidad Católica del Ecuador. A 2-m-wide median strip separates the northbound and southbound lanes. Northbound traffic travels up a ~ 10% grade at the study site. The nearest traffic light was ~ 100 m to the north, and a bus stop was ~ 50 m south of the site. The speed limit is 50 km/h, though the observed speed of vehicles varied depending on the time of day, lane of travel, and type of vehicle. Throughout the study there was partial cloud cover with brief showers (<30 min) occurring in the late afternoon on July 6 and July 8, and around noon on July 7. Winds were generally light (~ 1–3 m/s) and variable on each day of the study.

2.2. Equipment

The photoelectric aerosol sensors (PAS) were model PAS2000 Real-Time PAH Monitors (EcoChem Analytics; League City, TX). Their design and operation have been described elsewhere (Burtcher, 1992). Briefly, a vacuum pump draws air through a quartz tube around which a UV-lamp is mounted. Irradiation with UV light at $\lambda = 222$ nm causes particles to emit electrons, which are then captured by surrounding gas molecules. Negatively charged particles are removed from the airstream, and the remaining positively charged particles are collected on a filter mounted in a Faraday cage. The particle filter converts the ion current to an electrical current, which is then amplified and measured with an electrometer.

Measurements at El Camal and El Condado were made at 24-s intervals during which the lamp was on for 8 s and off for the next 16 s. One-minute average measurements were recorded on laptop computers using software developed by EcoChem Analytics. The sensors were attached to the inlet stacks within the air monitoring stations with Teflon tubing. Data was continuously collected except during routine maintenance and electrical failures (~ 30 days total at each site). Curbside measurements near Universidad Católica were made every 8.6 s during which the UV-lamp was on for 4.3 s and off for the next 4.3 s. No averaging of curbside measurements was done. The Teflon inlet tubing was 1.3 m above the street, and extended ~ 7 m to the sensor. For all measurements, the airflow through the sensors was 2.0 L min^{-1} , and the monitoring range was 1–2000 fA.

Field calibration studies have shown a nearly linear relationship between PAS signals and PAH levels measured in samples of particles filtered from ambient air (Hart et al., 1993; McDow et al., 1990; Agnesod et al., 1996; Ramamurthi and Chuang, 1997). A conversion factor of $\sim 0.5 \text{ ng/m}^3/\text{fA}$ was used to estimate particle-bound PAH concentrations based on PAS measurements. This conversion factor was developed in a study in Boston, Massachusetts (USA) (Dunbar et al., 2001), and is consistent with the manufacturer's recommended range of $0.3\text{--}1 \text{ ng/m}^3/\text{fA}$ (EcoChem, 1997).

In addition to polycyclic aromatic hydrocarbons, CO, SO₂, NO_x, air temperature, wind speed, and solar irradiation were measured continuously at both El Camal and El Condado, and PM_{2.5} was measured at El Camal. Wind speed was measured with Met One 010C wind speed sensors; temperature was measured with Vaisala temperature sensors; and measurements of solar irradiation were made with Kipp and Zonen CM3 pyranometers. CO was measured with Thermo Electron Model 48i CO analyzers, NO_x was measured with Thermo Electron Model 48C NO_x analyzers; and SO₂ was measured with Thermo Electron Model 43C SO₂ analyzers;

PM_{2.5} was measured using a Thermo Anderson FH42 Carbonium-14 Beta Gauge. The sampling frequency for CO, NO_x, SO₂, and PM_{2.5} was once every 10 s; the averaging time was 10 min. A video camera was used to record northbound traffic on Avenida 12 de Octubre as vehicles passed the curbside PAS.

2.3. Data reduction

During the traffic study, 49 h of video recordings were made of vehicles passing the curbside PAS. A log was created indicating the time, lane, and type of each vehicle. Vehicles were assigned to one of 12 types (Table 1). Over 20,000 PAS readings were recorded during the 4-d study. To determine whether there were correlations between PAS signals and individual vehicles, it was assumed that “peaks” in the PAS data represented PAH directly emitted from vehicles in the northbound lanes of Avenida 12 de Octubre. The term “peak” was defined by first performing an autocorrelation analysis to determine the minimum period of time between independent PAS readings for each day of the study. A span of ~ 7.2 min (54 readings) was found to yield statistically significant ($p > 0.95$) independence between individual measurements; thus, daily 54-reading moving averages (MA54) were calculated. For each hour of the study, a cumulative distribution function (CDF) of the MA54 record was then created to determine the hourly 95% critical level (CL5). If a PAS signal exceeded the hourly CL5, there was a 95% probability it was statistically significantly greater than the MA54, and it was thus defined as a “peak”.

There was a 4–24-s lag (travel time) between when a vehicle passed the PAS and when the sensor responded, depending on the vehicle’s travel lane. Vehicles traveling in the lane closest to the monitor (lane 1) tended to produce exhaust plumes that had relatively short lag times; vehicles traveling in lane 3 produced plumes that had longer lag times. The average exhaust plume took ~ 17 s to dissipate; therefore, it was assumed that if a vehicle passed the sensor 4–41 s (depending on its travel lane) before a CL5 peak was measured, then the vehicle could have contributed to the observed peak. The effects of wind speed and direction on lag times were not measured.

3. Results and discussion

3.1. Spatial and temporal variations in PAH concentrations

PAH concentration frequency distributions were non-Gaussian with many more low values than high ones (Fig. 2); therefore, median PAH values were used as the summary statistic for spatial and temporal comparisons. PAH levels were generally much higher at Universidad Católica than at either El Condado or El Camal. The median of all measurements at Universidad Católica was 220 ng/m³ (hourly medians ranged between 140 and 300 ng/m³), while at El Camal and El Condado the median concentrations were 32 ng/m³ (11–180 ng/m³) and 14 ng/m³ (5–58 ng/m³), respectively (Fig. 2). These differences are attributable to proximity of the monitoring equipment to sources of motor vehicle exhaust. The PAS at Universidad Católica was located ~1.3 m from the heavily traveled Avenida 12 de Octubre, whereas the sensors at El Condado and El Camal were both >10 m from the nearest roadways. These results are consistent with studies showing concentrations of traffic-related pollutants – e.g., particulate matter, CO – are measurably higher near busy urban roadways, but decrease significantly at distances >10–20 m from roadways (Fischer et al., 2000; Shi et al., 1999).

The higher levels of PAH at El Camal compared to El Condado may be attributable to differences in traffic patterns and the degree of urbanization at the two sites. El Camal, which was surrounded by many narrow streets, was frequented by heavy-duty trucks and diesel buses. In contrast, there were fewer streets near El Condado where the dominant PAH source appeared to be traffic emissions from a 4-lane roadway. The levels of other markers of vehicular

emissions – NO_x , SO_2 , and CO – were also generally higher at El Camal than El Condado (Fig. 3), which is consistent with the PAH data, and thus supports the conclusion that vehicle exhaust was a more dominant source at El Camal.

In addition to spatial variation, temporal variations in PAH levels were also observed. There was consistent diurnal variation in PAH levels, particularly at El Condado and El Camal (Fig. 2). At both sites PAH levels were elevated each day between 05:00 and 09:00 with maxima commonly occurring between 06:00 and 07:00. During these maxima, the median PAH levels at El Condado (58 ng/m^3) and El Camal (180 ng/m^3) were ~4-fold and ~5-fold, respectively, above their annual median values. PAH levels generally decreased throughout the rest of the day except at El Camal where there was an afternoon maximum (median = $\sim 60 \text{ ng/m}^3$) between 20:00 and 21:00. Diurnal variations are also evident at Universidad Católica, but the maxima are less pronounced compared to El Condado and El Camal. Weekly variations in PAH levels were also evident (Fig. 2): weekday concentrations were higher than weekend concentrations at all three sites. The ratio of weekday to weekend medians for El Condado, El Camal, and Universidad Católica were 1.6, 1.4, and 2.1, respectively. PAH levels during the wet season (June–September) were not significantly different than during the dry season (October–May) at either El Camal or El Condado (Fig. 4).

Diurnal PAH maxima in Quito appear to be exacerbated by atmospheric temperature inversions. Inversions occur when cold air masses build up at night over land surfaces and are effectively trapped as the sun rises and warms overlying air. Pollutants can accumulate in the cold, dense air layer until the sun warms the land surface causing the air masses to mix by convection. This phenomenon is illustrated in Fig. 5, which shows the changes in PAH concentrations at El Condado and El Camal relative to changes in solar irradiation, temperature, and wind speed. After gradually decreasing overnight, the change in air temperature at both sites turned positive after ~05:00. PAH levels also increased after 05:00 (reflecting early morning traffic and possibly cooking emissions), but after about 07:00, as sunlight began to warm the valley and the winds started to pick up, the change in PAH levels turned negative indicating that significant atmospheric mixing had occurred. Other pollutants measured at El Camal and El Condado behaved similarly: concentrations of CO , SO_2 , NO_x , and $\text{PM}_{2.5}$ reached daily maxima between 06:00 and 08:00, and decreased sharply after 08:00 (Fig. 3).

3.2. PAH in emissions from motor vehicles

PAH data collected during the traffic study at Universidad Católica are summarized in Fig. 6. Concentrations ranged from $\sim 0 \text{ ng/m}^3$ to 1000 ng/m^3 , the maximum detection limit of the sensor. Median PAH levels for each day of monitoring were between $\sim 120 \text{ ng/m}^3$ on Saturday, 10 July, and $\sim 300 \text{ ng/m}^3$ on Wednesday, 7 July. Median PAH concentrations for each hour of monitoring (over all four days) were between 40 and 340 ng/m^3 .

Over 41,000 vehicles passed the PAH sensor during the traffic study (Table 1 and Fig. 6). On weekdays there appeared to be two traffic-volume maxima: one in the morning from 08:30 to 09:30 (average = ~ 1000 vehicles), and another between 17:30 and 18:30 (average = ~ 990 vehicles). In between the two maxima the traffic volume was $\sim 850 \text{ vehicles h}^{-1}$. These maxima were not observed on Saturday. On weekdays the average traffic volume ($971 \text{ vehicles h}^{-1}$) was nearly twice as high as on Saturday ($534 \text{ vehicles h}^{-1}$). In comparing the three weekdays, there was little variation in total or hourly traffic volumes.

The majority of the vehicles passing the sensor were passenger cars (36%), taxis (21%), buses (19%), and SUVs (13%). Other vehicles included pickup trucks (6.7%), motorcycles (2.1%), minivans (1.2%), vans (0.08%), minibuses (0.52%), small trucks (0.65%), medium trucks (0.75%), and large trucks (0.28%). The numbers of buses, vans, and large trucks were fairly constant on all days (Table 1); however, on Saturday the numbers of cars, taxis, and SUVs

were ~50% lower compared to the weekdays. This decrease likely explains the lower PAH levels observed on Saturday compared to weekdays (Fig. 2). The composition of the vehicle fleet remained fairly consistent on weekdays (Fig. 6). On average ~160 buses h⁻¹ passed the site on weekdays, while on Saturday ~140 buses h⁻¹ passed the site, a decrease of 14%. Many individual buses passed the monitoring site several times per day, which explains the higher than expected percentage of buses in our study population. (A 2003 census indicated that buses were ~2% of the registered vehicles in Quito (Corpaire, 2006a)).

In general, maximum hourly CL5 values did not change as a function of the total number of vehicles passing the sensor, nor did they appear to depend on the fleet composition (Fig. 6). The only time the maximum hourly CL5 value correlated with the maximum number of vehicles was 6 July, between 08:30 and 09:30. In contrast, on Saturday, 10 July, the lowest hourly CL5 value corresponded to 13:30–14:30, the hour that the maximum number of vehicles passed the sensor. Thus, traffic volume alone did not account for elevated PAH levels, suggesting that other factors (e.g., disproportionately high number of vehicles without catalytic converters, meteorological conditions) also influenced PAH levels at the site.

Nearly 26% of all PAS readings exceeded the hourly CL5 value and were thus considered “peaks”. Of the total CL5 peaks attributable to specific vehicles, passenger cars accounted for 35%, taxis and buses each accounted for ~20%, SUVs accounted for ~13%, and pickup trucks 6.5% (Table 1). Between 30 and 43% of vehicles of each type were associated with peaks, indicating the chance that a given vehicle passing the PAS contributed to a CL5 peak was ~33%. This finding was unexpected: buses frequently had visible exhaust plumes, however, they contributed to peaks only slightly more often than average, 39% of the time.

In comparing the vehicle and PAH datasets we found that our results were sensitive to the choice of exhaust plume lag time but not to the critical level. It was assumed that emissions from all vehicles traveling northbound along Avenida 12 de Octubre could be measured by the PAS (i.e., the maximum lag time between when a vehicle passed the PAS and its exhaust plume was measured was 41 s). To test the sensitivity of our results to this assumption, all vehicles that traveled in lane 3 (which was farthest from the PAS) were removed from the fleet record (i.e., lag time = 27 s). Because cars, SUVs, and pickup trucks most frequently used lane 3 and buses and taxis used lanes 1 and 2, when lane 3 traffic was removed the fractions of all vehicles that contributed to CL5 peaks that were accounted for by cars, SUVs, and pickup trucks dropped by about one-third each, while the fractions accounted for by buses rose from 21% to 34% and by taxis rose from 20% to 22%. However, the percentage of vehicles of a given type that contributed to peaks (~33%) was unchanged when lane 3 traffic was removed. We also calculated the CL1 (99%) and CL10 (90%) threshold levels and compared the results obtained with these new levels to those obtained with the CL5. In doing so, we found that the results were largely insensitive either to increasing (CL1) or to decreasing (CL10) the critical level.

3.3. Significance

Our results show that atmospheric temperature inversions contribute to elevated PAH levels in Quito. At El Camal and El Condado median PAH levels between 06:00 and 08:00, just before breakup of daily inversions, were 2–3-fold higher than afternoon minima, and 10–16-fold higher than 02:00–03:00 when PAH levels were at their lowest. Daily concentration maxima were also observed for NO_x, SO₂, CO, and PM_{2.5} just before the breakup of temperature inversions. These findings are consistent with studies in other urban areas where inversions have been studied. For example, Chow et al. (2002) suggested that PM_{2.5} and PM₁₀ concentration maxima in the morning in Mexico City resulted from accumulation of fresh vehicle emissions beneath surface inversions. Kukkonen et al. (2005) reported that temperature inversions and atmospheric stability were among the best predictors of PM₁₀ levels in Helsinki, London, Milan, and Oslo. Reisen and Arey (2005) attributed higher morning PAH

levels in Los Angeles during the winter to seasonal differences in meteorology, and, in particular, more frequent surface inversions in the winter compared to the summer. The consistency of the timing and recurrence of the pollutant spikes observed during our year-long study in Quito appears to be due to the relative constancy of both the main pollution source (vehicle emissions) and surface inversions in the Quito area.

PAH levels were generally much higher at Universidad Católica compared to El Camal and El Condado; however, the effects of inversions on PAH levels at Universidad Católica were less pronounced. These findings suggest that near major roadways vehicle exhaust source strength is a more important determinant of pollutant levels than atmospheric mixing. Results from other cities highlight the importance of vehicular emissions as a source of PAH at the local scale. For example, Sapkota and Buckley (2003) found that median PAH concentrations near the Baltimore Tunnel (Baltimore, MD, USA) were 9–200 ng/m³, and Marr et al. (2004) reported that median hourly PAH levels near roadways in Mexico City were 60–910 ng/m³. PAH levels in these studies were comparable to street-level measurements in Quito (40–340 ng/m³).

In contrast, PAH levels were much higher at street level in Quito than in Boston where PAS have also been used to measure PAH levels (Dunbar et al., 2001). Median daily PAH levels at street level in downtown Boston were ~5–10 ng/m³ as compared to 120–300 ng/m³ at Universidad Católica. These differences likely result from the numbers and kinds of vehicles at the two sites. The traffic volume at the Boston site was ~33% lower than in Quito, and the Boston fleet was ~94% gasoline-powered passenger vehicles (cars, SUVs, pickup trucks, and taxis) and <2% buses, whereas the Quito fleet was ~77% passenger vehicles and 19% buses. In addition, >95% of passenger cars in Boston were equipped with catalytic converters compared to only ~45% in Quito (Corpaire, 2006a). Other factors that likely affected the results in Quito were topography and altitude. Due to hilly terrain and low oxygen levels, Quito drivers often increase the fuel flow to their engines to boost power. Rich fuel-to-air mixtures typically generate higher amounts of PAH than leaner mixtures (Jensen and Hites, 1983).

Compared to conventional methods for quantifying particle-bound PAH in ambient air, PAS offer advantages in terms of ease of data collection and high frequency of measurement; however, some disadvantages should be noted. One is that PAS only measure total particle-bound PAH and not individual compounds like benzo[a]pyrene, cyclopenta[cd]pyrene, and other highly genotoxic species. Wasserkort et al. (1996) addressed this by comparing PAS measurements from a diesel engine, a parking garage, and urban air with simultaneously collected samples of particles that were tested for genotoxicity in a bacteria assay. A linear relationship between PAS measurements and genotoxicity was reported ($r^2 = 0.82$) indicating that PAS measure genotoxic PAH in complex mixtures. Another potential limitation is that the contribution of individual PAH to the total photoemission signal may not be directly proportional to their concentration. For example, triphenylene and chrysene, which both have high first ionization potentials, are not easily photoionized, while coronene and benzo[a]pyrene produce strong photoemissions signals (Niessner, 1986). Thus, particles containing the same total mass of PAH may produce different photoemission signals depending on the chemical properties of the sorbed PAH. A related problem has to do with secondary aerosol formation and loss of photoemission signal. Marr et al. (2006) observed a more rapid decrease in PAS measurements compared to bulk PAH concentrations (measured by aerosol mass spectrometry) during the late morning in Mexico City, and hypothesized that freshly emitted combustion-related particles were quickly coated by secondary aerosol material, thus diminishing the PAS signal. Despite these drawbacks, PAS are useful for monitoring short-term differences in PAH levels in a given area.

Our results suggest that people who live, work, or otherwise spend substantial time near busy roadways in Quito are exposed to high levels of PAH. This is consistent with the results of Estrella et al. (2005), who showed that blood carboxyhemoglobin levels were highest among Quiteños who live near busy roadways. Taken together, these studies suggest that Quiteños may be at risk of health effects relating to vehicular air pollution. In addition, we showed that due to driving patterns and atmospheric inversions, the highest levels of traffic pollutants in Quito occur in the morning just after the start of rush hour and for 1–2 h until the inversions lift. This finding, and knowledge of which vehicle types contribute the highest amounts of air pollutants, may help to inform air quality management efforts in Quito.

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Fig. 1.
Location of monitoring stations in Quito.

Fig. 2.

Box-plots of hourly PAH levels measured on weekdays and weekends at El Condado, El Camal, and Universidad Católica. Monitoring at El Condado and El Camal was done continuously from March 4, 2004 to February 28, 2005; monitoring at Universidad Católica was done during daylight hours on July 6–8 and July 10, 2004. Shaded boxes represent the 25th through 75th percentiles; whiskers extend to the 10th and 90th percentiles; black dots represent the 5th and 95th percentiles; solid lines represent medians.

Fig. 3.

Box-plots of hourly PAH, CO, SO₂, NO_x, and PM_{2.5} levels measured at El Condado and El Camal. PAH monitoring was done from March 4, 2004 to February 28, 2005; CO, SO₂, and NO_x were monitored from March 1 to December 31, 2004; PM_{2.5} monitoring was done from August 27 to December 31, 2004 at El Camal only. Shaded boxes represent the 25th through 75th percentiles; whiskers extend to the 10th and 90th percentiles; black dots represent the 5th and 95th percentiles; solid lines represent medians.

Fig. 4.

Seasonal average hourly ambient PAH levels at (a) El Condado and (b) El Camal. The wet season graphs comprise data collected from June through September 2004. The dry season graphs comprise data collected from March to May 2004 and October 2004–February 2005. Shaded box indicates 25th and 75th percentiles; whiskers indicate 10th and 90th percentiles; dots represent 5th and 95th percentiles; solid lines represent medians.

Fig. 5.

The top panels show hourly median values of solar irradiation (SR), temperature (T), and wind speed (WV) at El Condado and El Camal (March 2004–February 2005). The bottom panels show the change in hourly median temperatures and PAH concentrations as a function of time.

Fig. 6. Box-plots of hourly PAH levels and bar-charts of vehicles measured at Universidad Católica. Monitoring was done during daylight hours on July 6–8 and July 10, 2004. Shaded boxes represent the 25th through 75th percentiles; whiskers extend to the 10th and 90th percentiles; black dots represent the 5th and 95th percentiles; solid lines represent medians. The large amount of traffic after 17:30 on July 8, 2004 was due to a local entertainment event.

Vehicles counted during the 4-day traffic study at Avenida 12 de Octubre near Universidad Católica.

Vehicle type	Total vehicle count ^a				Weekdays		Weekend		Overall		Contributing to peaks		
	Lane 1	Lane 2	Lane 3	Total	Average count per hour	Percent of total	Average count per hour	Percent of total	Average count per hour	Percent of total	Number of vehicles	Percent of total	Percent of vehicle type
Cars	1132	5384	8394	14,910	352	36%	175	33%	308	36%	4976	35%	34%
SUVs	422	1841	3085	5348	126	13%	61	12%	110	13%	1834	13%	35%
Pickups	159	975	1662	2796	65	6.7%	36	6.8%	58	6.7%	933	6.5%	34%
Motorcycles	82	381	421	884	22	2.2%	8.1	1.5%	18	2.1%	290	2.0%	33%
Taxis	1380	4114	3211	8705	205	21%	96	18%	178	21%	2930	20%	34%
Mimivans	20	177	310	507	12	1.2%	6.5	1.2%	11	1.2%	161	1.1%	32%
Vans	2	14	17	33	0.69	0.07%	0.58	0.11%	0.67	0.08%	13	0.09%	39%
Mimibuses	11	59	150	220	5.4	0.55%	1.8	0.33%	4.5	0.52%	82	0.57%	38%
Buses	3294	3963	471	7728	166	17%	141	26%	160	19%	2967	21%	39%
Small trucks	19	102	153	274	6.6	0.68%	2.8	0.52%	5.6	0.65%	89	0.62%	33%
Med. trucks	31	128	156	315	7.7	0.79%	2.8	0.52%	6.5	0.75%	106	0.74%	34%
Large trucks	6	51	59	116	2.6	0.27%	1.8	0.33%	2.4	0.28%	32	0.22%	28%
Total	6558	17,189	18,089	41,836	971	100%	534	100%	862	100%	14,413	100%	

^aVehicles passed the PAS inlet in lane 1 (closest to inlet), lane 2, or lane 3 (farthest from inlet). Weekday counts per hour were averaged over 3 days; weekend day counts per hour were averaged over 1 day (Saturday). Vehicles were counted from 06:30 to 18:30 on 6–8 and 10 July 2004. Registered passenger vehicles (cars, SUV s, taxis, and pickup trucks) and buses make up ~85% and ~2%, respectively, of the total vehicle fleet in Quito (Corpaire, 2006a); thus, based on the data in this table as well as our video records, it is evident that many vehicles, particularly buses, passed the monitoring site multiple times during the study period.