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Particulate matter and carbon monoxide multiple regression models using environmental characteristics in a high diesel-use area of Baguio City, Philippines

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Abstract

In Baguio City, Philippines, a mountainous city of 252,386 people where 61% of motor vehicles use diesel fuel, ambient particulate matter <2.5 µm ($PM_{2.5}$) and <10 µm (PM_{10}) in aerodynamic diameter and carbon monoxide (CO) were measured at 30 street-level locations for 15 min apiece during the early morning (4:50–6:30 am), morning rush hour (6:30–9:10 am) and afternoon rush hour (3:40–5:40 pm) in December 2004. Environmental observations (e.g. traffic-related variables, building/roadway designs, wind speed and direction, etc.) at each location were noted during each monitoring event. Multiple regression models were formulated to determine which pollution sources and environmental factors significantly affect ground-level $PM_{2.5}$, PM_{10} and CO concentrations. The models showed statistically significant relationships between traffic and early morning particulate air pollution [($PM_{2.5}$ $p=0.021$) and PM_{10} ($p=0.048$)], traffic and morning rush hour CO ($p=0.048$), traffic and afternoon rush hour CO ($p=0.034$) and wind and early morning CO ($p=0.044$). The mean early morning, street-level $PM_{2.5}$ (110 ± 8 µg/m^3; mean ±1 standard error) was not significantly different (p-value>0.05) from either rush hour $PM_{2.5}$ concentration (morning$=98\pm7$ µg/m^3; afternoon$=107\pm5$ µg/m^3) due to nocturnal inversions in spite of a 100% increase in automotive density during rush hours. Early morning street-level CO (3.0 ± 1.7 ppm) differed from morning rush hour (4.1 ± 2.3 ppm) ($p=0.039$) and afternoon rush hour (4.5 ± 2.2 ppm) ($p=0.007$). Additionally, $PM_{2.5}$, PM_{10}, CO, nitrogen dioxide (NO_2) and select volatile organic compounds were continuously measured at a downtown, third-story monitoring station along a busy roadway for 11 days. Twenty-four-hour average ambient concentrations were: $PM_{2.5}=72.9\pm21$ µg/m^3; CO$=2.61\pm0.6$ ppm; $NO_2=27.7\pm1.6$ ppb; benzene$=8.4\pm1.4$ µg/m^3; ethylbenzene$=4.6\pm2.0$ µg/m^3; *p*-xylene$=4.4\pm1.9$ µg/m^3; *m*-xylene$=10.2\pm4.4$ µg/m^3; *o*-xylene$=7.5\pm3.2$ µg/m^3. The multiple regression models suggest that traffic and wind in Baguio City, Philippines significantly affect street-level pollution concentrations. Ambient $PM_{2.5}$ levels measured are above USEPA daily (65 µg/m^3) and Filipino/USEPA annual standards (15 µg/m^3) with concentrations of a magnitude rarely seen in most countries except in areas where local topography plays a significant role in air

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pollution entrapment. The elevated pollution concentrations present and the diesel-rich nature of motor vehicle emissions are important pertaining to human exposure and health information and as such warrant public health concern.

Keywords: Air pollution; Traffic; Particulate matter; Carbon monoxide; Nitrogen dioxide; Volatile organic compounds; Ambient; Wind; Diesel; Inversion

1. Introduction

Ambient air pollution, which includes but is not limited to particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs) and nitrogen oxides (NOx), is a major environmental health problem present within a variety of urban and rural settings. Although high air pollution concentrations have been documented within rural areas (Hassan et al., 1995; Naeher et al., 2007; Reinhardt et al., 2001), ambient air pollution is most prevalent within urban areas potentially resulting in large-scale exposures within the residing population. The World Health Organization (WHO) estimates that 1.5 billion urban dwellers live in areas with levels of outdoor air pollution above the maximum recommended limits (WHO, 2005).

Epidemiological studies have shown a positive correlation between exposure to air pollutants and morbidity/mortality including asthma, chronic obstructive pulmonary disease, cardiovascular disease, lower birth weights, cancer, and premature births (ATSDR, 1997; Dockery et al., 1993; HEI, 2001; WHO, 2000). In Asia alone over 500,000 people die each year from diseases related to air pollution (WHO, 2005). Furthermore, studies have shown that particulates generated from combustion processes, especially diesel exhaust particulates, are more toxic and often result in more exacerbated health effects than those from non-combustion processes (Bremner et al., 1999; Brunekreef et al., 1997; Hoek et al., 2000; South Coast, 2000; Van Vliet et al., 1997).

Although there is a steadily growing air pollution study database, personal air pollution exposures have not been adequately studied and documented in many developing countries. For example, the only air pollutant that has been historically monitored within the Philippines is total suspended particulates (TSP), which incorporates all PM less than 50 μm in aerodynamic diameter. However, studies have shown that particles less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$) are primarily responsible for most of the particle-related health effects (Dockery et al., 1993; HEI, 2001). Even though the 1999 Philippine Clean Air Act set ambient standards for PM_{10}, NO_2, and CO, multiple parts of the country including Baguio City have not fully complied with these new monitoring requirements as of the time of this study due to limited resources (Republic of the Philippines, 2003).

Data collected in the downtown area of Baguio City, Philippines (Central Business District or CBD) in 2000 and 2001 indicated that Baguio was one of the most polluted cities within the Philippines with respect to PM (World Bank, 2002), much of which was derived from diesel-fueled motor vehicles [(61% of the 22,713 registered vehicles in Baguio use diesel) (Baguio DOTC, 2003)]. Additionally, unleaded gasoline was introduced in the Philippines in February 1994 and leaded gasoline was nationally phased out in 2000. The motor vehicles present that formerly used leaded gasoline were not equipped with catalytic converters and therefore would release a higher level of VOCs and NOx during the combustion of unleaded gasoline (Hoekman, 1992). Due to the importance of Baguio as a tourism and educational hub within the northern Philippines, it is important to characterize the city's air quality and to identify potential air pollution sources.

Adequate air pollution exposure studies can be costly which may prove to be a limiting factor for many areas, particularly within developing countries. Therefore, a low-cost study design that could sufficiently predict pollutant concentrations primarily using environmental variables may prove to be suitable for areas that could not afford the equipment and personnel needed for a full air pollution study.

The objectives of this study were: 1) to identify the most predictive environmental observation variables in urban, diesel-rich areas of Baguio City, Philippines in relation to $PM_{2.5}$, PM_{10} and CO concentrations during periods associated with varying motor vehicle densities and nocturnal inversions and; 2) to monitor ambient concentrations of selected air pollutants [$PM_{2.5}$, PM_{10}, CO, NO_2 and selected VOCs (BTEX: benzene, toluene, ethylbenzene and xylenes)] in downtown Baguio City in order to determine diurnal pollution patterns.

2. Methods

2.1. Study location

This study was conducted December 13–25, 2004 in Baguio City, Philippines. Baguio City, a city of 252,386 people as of 2000, is located at 16°N and 120°E on the island of Luzon in the Pacific Ocean 125 miles north of Manila approximately 5000 ft above sea level within the Cordillera Mountains. Baguio's elevation and corresponding cooler temperature (mean annual temperature of 68 °F) result in a regular flow of visitors from the lowlands, especially Manila. During the peak of the tourist influx, particularly during Lent (February to April), transients triple the Baguio population (WOW-Philippines, 2005).

Baguio City's CBD is located at the bottom of a mountain basin where airflow is partially impeded by the surrounding mountains resulting in an increase in frequency and intensity of nocturnal inversions, a reversal in the normal temperature lapse rate during the night with the temperature rising with increased elevation instead of falling. The asphalt-paved streets within the CBD are generally lined with buildings of two or three stories with some as high as ten stories. Approximately half the area of the city has a slope of 25% or more (WOWPhilippines, 2005). The CBD is home to a variety of activities including but not limited to educational establishments (primary, secondary and universities), hospitals, commercial businesses, restaurants and offices/professional activities.

2.2. Street-level monitoring and environmental variables

Thirty sites (Fig. 1) within the CBD covering various levels of pedestrian, automotive and commercial activities were selected based on the general locations used in a previous study examining the impact of urban environmental features and economic status on the health conditions of 187 street vendors working within Baguio City's CBD (Akers et al., 2004). Street-level, real-time $PM_{2.5}$, PM_{10} and CO were measured and environmental observational data were collected at each site during three monitoring periods on weekdays between December 13

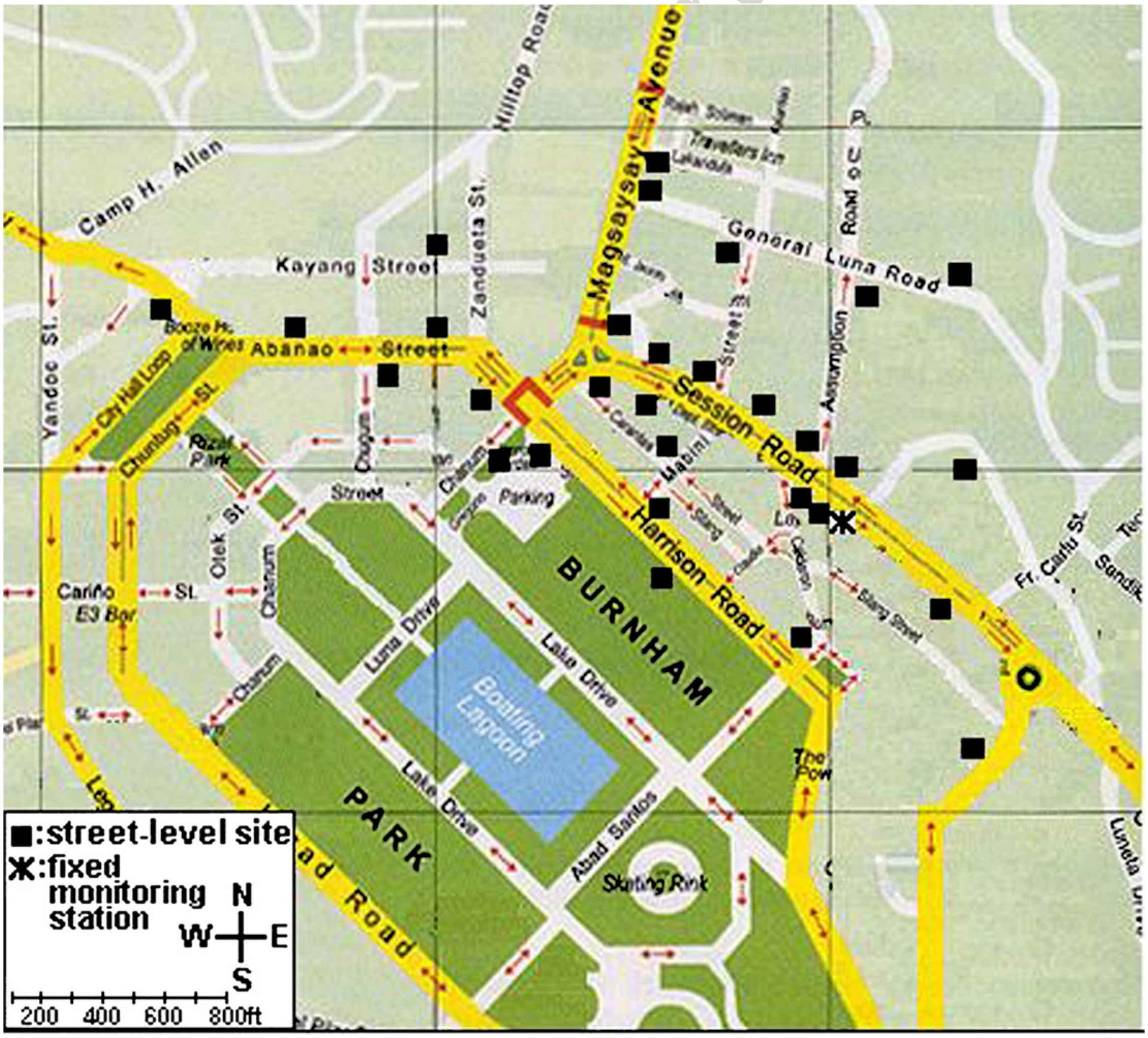

Fig. 1. Location of fixed monitoring site and 30 street sites within downtown Baguio City, Philippines.

and 22, 2004. Preliminary ambient pollution data collected at the fixed-site monitoring station and traffic observations within the CBD were used to select the three monitoring periods. Fifteen minutes of continuous, real-time data were collected once at each site between 4:50 and 6:30 am (a period of low automotive density and limited vertical atmospheric mixing), 6:30–9:10 am (morning rush hour with low to moderate atmospheric mixing including residual air pollutants returning to the ground in visible sheets after the nocturnal inversion breakup) and 3:40–5:40 pm (afternoon rush hour with moderate to high atmospheric mixing). Although the afternoon ambient pollution concentrations measured at the fixed-site monitoring station peaked at approximately 6 pm, street-level sampling ended by 5:40 pm (sunset) to ensure technician safety.

Real-time $PM_{2.5}$ and PM_{10} concentrations at each monitoring site were measured using laser photometer aerosol monitors with dataloggers (DustTrak-TSI Inc., model 8520) while real-time CO concentrations were measured in duplicate using Langan CO monitors (Langan Products Inc., model T15v). All monitors were located in or attached to a backpack with the sensor/air intake located at the chest of the investigator carrying the equipment (approximately 1.5 m from the ground and 2 m from the closest road lane).

Thirteen environmental characteristics were noted at each of the 30 sites during each sampling period (Table 1). Automobiles and people were counted if they crossed a predetermined line perpendicular to the road in front of the monitoring site. If the site was located at the corner of an intersection of two roads, counts included the quantity from both roads. Upwind, non-motor vehicle pollution sources primarily included street vendors cooking with liquid petroleum gas, kerosene or coal and restaurants/bakeries cooking with natural gas or electricity within 20 m.

2.3. Fixed-site monitoring station

A fixed monitoring station was established to collect ambient $PM_{2.5}$ (real-time and time-integrated), PM_{10} (real-time), CO (real-time), NO_2 and BTEX VOCs (both passive diffusion, time-integrated) concentrations throughout the 11-day sampling period. The monitoring station was located on a third floor windowsill underneath an awning facing Session Road, a major six-lane road within Baguio's CBD that acts as the commercial artery of Baguio.

Table 1
Environmental observation variables used to characterize the 30 street-level sites within Baguio City, Philippines

Variable description	Scale	Levels for dichotomous and ordinal variable	Cluster title
Gasoline-powered vehicles per minute	Continuous	–	Traffic Principle Component
Diesel-powered vehicles per minute	Continuous	–	
Total motor vehicles per minute	Continuous	–	
People per minute (foot traffic)	Continuous	–	
Presence/absence of a stop sign/light, traffic cop, or other means to stop traffic	Dichotomous	0 = Absent, 1 = present	
Traffic flow	Ordinal	0 = Traffic is moving smoothly, 1 = traffic is moving, but not smoothly, 2 = traffic is backed up	
Width of road in meters from sidewalk to sidewalk	Continuous	–	Roadsize Principle Component
Number of lanes in the road	Continuous	–	
Presence/absence of a median in roadway	Dichotomous	0 = No median present, 1 = median present	
Average number of building stories present in immediate surroundings	Continuous	–	Average Building Story
Presence/absence of appreciable wind	Dichotomous	0 = Wind absent, 1 = wind present	Wind
Presence/absence of upwind, non-motor vehicle-related pollution sources within 20 m	Dichotomous	0 = Absent, 1 = present	Upwind Pollution Source
Presence/absence of hilly terrain	Dichotomous	0 = Absent, 1 = present	Hill
Sampling period during which measurements were taken	Nominal	0 = Early morning, 1 = morning rush, 2 = afternoon rush	–

Twenty-four-hour time-integrated $PM_{2.5}$ samples were collected in duplicate using 37 mm Teflon filters (Pall, Teflon 2.0 μm pore size), Harvard Impactors (Air Diagnostics & Engineering Inc.) and SKC universal pumps (SKC Inc. model 224-PCXR8). Sampled filters were frozen during all storage and transportation periods to prevent volatilization. Filters were desiccated in climate-controlled conditions (20.6±1.4 °C; 31.0±13.4% relative humidity) for a 48-hour period prior to the weighing of the filters. Each filter was weighed twice before and after sampling following the EPA's Quality Assurance Guidance Document (USEPA, 1998) using a Cahn C-35 microbalance with 0.1 μg sensitivity. Air densities during weighing sessions corrected for temperature and atmospheric pressure, nominal densities of calibration masses, and control filters were used to adjust the balance readings for the buoyancy effect of air (Koistinen et al., 1999).

Real-time $PM_{2.5}$ and PM_{10} levels were measured with DustTrak aerosol monitors. At the beginning of the study the four DustTraks (two for the Session Road monitoring station and two for the 30 street-level sites) operated in parallel for 20 h (8 and 12 h with $PM_{2.5}$ and PM_{10} inlets, respectively) in Baguio City in order to determine and control for inter-instrument variation. Additionally, a concentration ratio was established comparing the average daily real-time and gravimetric $PM_{2.5}$ concentrations at the fixed monitoring station throughout the entire sampling period in order to adjust the real-time concentrations to increase comparability between the two sampling methods.

Real-time CO levels were continuously measured using a Langan CO monitor (Langan Products Inc., model T15v). The CO monitors were calibrated at the University of Georgia at the beginning and the end of the study with a zero gas and a 100 ppm CO gas. Both real-time CO and PM monitors operated in parallel and logged their respective mean concentrations at 30-second intervals.

Nitrogen dioxide was measured using Palmes Tubes (Palmes et al., 1976), all of which sampled for 72-hour periods. NO_2 concentrations were determined spectrophotometrically using a UV–VIS spectrophotometer (Milton Roy Company, Spectronic 20D) and a ten-point, cubic-spline fit calibration curve. The analytical limit of detection, determined using the standard deviation of field blank absorption, corresponded to 4 ppb for a 72-hour sampling period.

VOCs were collected using passive diffusion stainless steel tubes (90 mm long, 6.3 mm OD and 5 mm ID, Perkin-Elmer) packed with Tenax™ TA (60/80 mesh, 200 mg) as the absorbing medium. Each VOC tube had a 72-hour sampling period corresponding to the same sampling period of each Palmes Tube. VOC samples were analyzed using an automated thermal desorption system (Markes Unity) coupled to a ThermoElectron TRACE DSQ GC/MS. Sample volumes were calculated from the passive uptake rate of 0.54 mL/min (Brown et al., 1993; Brown and Crump, 1998, 1998; Brown, 2000).

2.4. Statistical analysis

Four environmental variables (nearby upwind non-motor vehicle pollution source, wind, road width, and people per minute) contained at least one missing value among the monitoring sites. Multiple imputation was used to fill in the missing values (Schafer, 1997) using PROCs MI and MIANALYZE in SAS version 9.1, and the results were pooled to account for and reduce the additional error introduced by estimating the missing data. The predictive mean matching method (Schenker and Taylor, 1996) was used for continuous variables (road width and people per minute) and the logistic regression method of imputation (Rubin, 1987) was used for the dichotomous variables (wind and non-motor vehicle pollution source).

Since several of the environmental variables suffered from substantial multicollinearity it was necessary to reduce the dimensionality of the predictor variables. Variable clustering techniques were used in order to avoid invalid statistical inferences often seen with backward, forward, and step-wise selection (e.g. confidence intervals too wide, p-values too small, detection of spurious relationships, etc.) (Harrell, 2001). Variable clustering methodology was implemented using PROC VARCLUS in SAS (Harrell, 2001; Khatree and Naik, 2000) where all variables are placed in a single cluster that is split until a stopping criterion is reached. Conceptually, this procedure uses an objective method to split all clusters in which more than one underlying dimension is represented. This is done in several steps where at each step the cluster whose second dimension is largest is chosen for splitting. Cluster splitting terminates when all clusters have second eigenvalues less than 1. After variable clustering each of the main clusters identified is represented in the analyses by the first principal component of the variables belonging to that cluster which explains at least 75% of the variability of the environmental variables within the cluster (Table 1). Several variables were not found to cluster strongly with other variables and were therefore analyzed individually (average building story, presence of hills, presence of wind, and nearby non-vehicle pollution source).

Linear mixed-effect multiple regression models were fitted of the form:

$$y_{ij} = \beta_{0j} + b_i + \beta_{1j}X_{1ij} + \beta_{2j}X_{2ij} + \ldots + \beta_{6j}X_{6ij} + e_{ij;}\ i = 1, \ldots, 30;\ j = 1, 2, 3$$

for the early morning, morning rush hour and afternoon rush hour average concentrations of CO, PM_{10} and $PM_{2.5}$. Here, y_{ij} is the response (lnCO, lnPM_{10}, or ln$PM_{2.5}$) for the ith site during the jth measurement period. X_{1ij},…,X_{6ij} are the environmental observation explanatory variables, and β_{0j}, β_{1j},…, β_{6j} are intercept and parameter estimates specific to the jth period. In addition, b_i is a normally distributed, site-specific random effect with zero mean and constant variance to account for within-site correlations among repeated measures taken at each site over the three measurement periods, and e_{ij} is a mean 0, constant variance, normal error term. Models were fit to each imputed data set using SAS PROC MIXED and then combined with PROC MIANALYZE. Because all three pollutant concentration variables exhibited strong heteroscedasticity, each response variable was modeled on the log scale which was successful in stabilizing the variance in the response.

$PM_{2.5}$, PM_{10} and CO concentrations at each of the 30 individual street-level sites and during each monitoring period were compared for a difference in mean pollutant measurements using a least significant difference (LSD) test.

3. Results

3.1. Sampling Period Selection and Corresponding Pollution Concentrations

Traffic and commercial activities as well as preliminary ambient air pollution data within the CBD were used in the selection of both high (6:30–9:10 am, 3:40–5:40 pm) and moderately low PM and CO concentration (4:50–6:30 am) sampling periods. The high pollution sampling periods, both corresponding to rush hour periods, occurred during the day while the majority of the early morning sampling period occurred before sunrise. Although the motor vehicle density during the early morning sampling period was approximately one half of that present during the rush hours, the $PM_{2.5}$ and PM_{10} mean concentrations among the 30 sites were not significantly different among the three monitoring periods ($p>0.05$, $\alpha=0.05$) (Table 2). The corresponding street-level CO concentrations among the 30 sites statistically differed between early morning and morning rush hour ($p=0.039$) and early morning and afternoon rush hour ($p=0.007$) (Table 2).

Real-time concentrations measured at the Session Road monitoring station indicated that on average the lowest one-hour average ambient $PM_{2.5}$ concentration at the Session Road station during the day (6:15 am to 5:30 pm) was 24.8 μg/m^3 (9:45–10:45 am) while the lowest average one-hour $PM_{2.5}$ concentration during the night (5:30 pm–6:15 am) was 43.4 μg/m^3 (2:45–3:45 am). The lowest one-hour average ambient $PM_{2.5}$ during the night was 75% higher than the day in spite of more vehicular, residential and commercial activities occurring during the day (Fig. 2).

3.2. Linear mixed-effect multiple regression modeling

The pooled results of the ln(CO), ln($PM_{2.5}$) and ln (PM_{10}) multiple regression analyses appear in Table 3. The parameter estimates (β) listed in the table represents the pollutants' multiplicative effects in relation to the environmental variable or cluster listed. For example, a parameter estimate of −0.482 represents a multiplicative effect of $e^{-0.482}$ (38% decrease in pollution concentration). The explanatory variables within the CO multiple regression models containing significant parameter estimates were Wind in the early morning (parameter

Table 2
Mean $PM_{2.5}$, PM_{10}, CO and automotive counts for all 30 monitoring sites by sampling period

		$PM_{2.5}$ (μg/m^3)	PM_{10} (μg/m^3)	CO (ppm)	Gasoline autos/min	Diesel autos/min
Early morning (4:50–6:30 am)	Average±standard error	110±14	118±14	3.0±1.7	2.5±1.6	10.4±6.5
	Maximum	240	272	5.3	5.0	23.1
	Minimum	50	54	1.9	0.0	0.1
Morning rush hour (6:30–9:10 am)	Average±standard error	98±13	124±20	4.1±2.3	6.6±3.9	18.7±9.5
	Maximum	274	55	9.8	20.9	41.9
	Minimum	42	48	2.2	0.3	0.9
Afternoon rush hour (3:40–5:40 pm)	Average±standard error	107±10	117±11	4.5±2.2	6.6±3.8	20.5±10.6
	Maximum	287	300	11.2	18.0	44.1
	Minimum	47	52	2.4	0.1	1.8

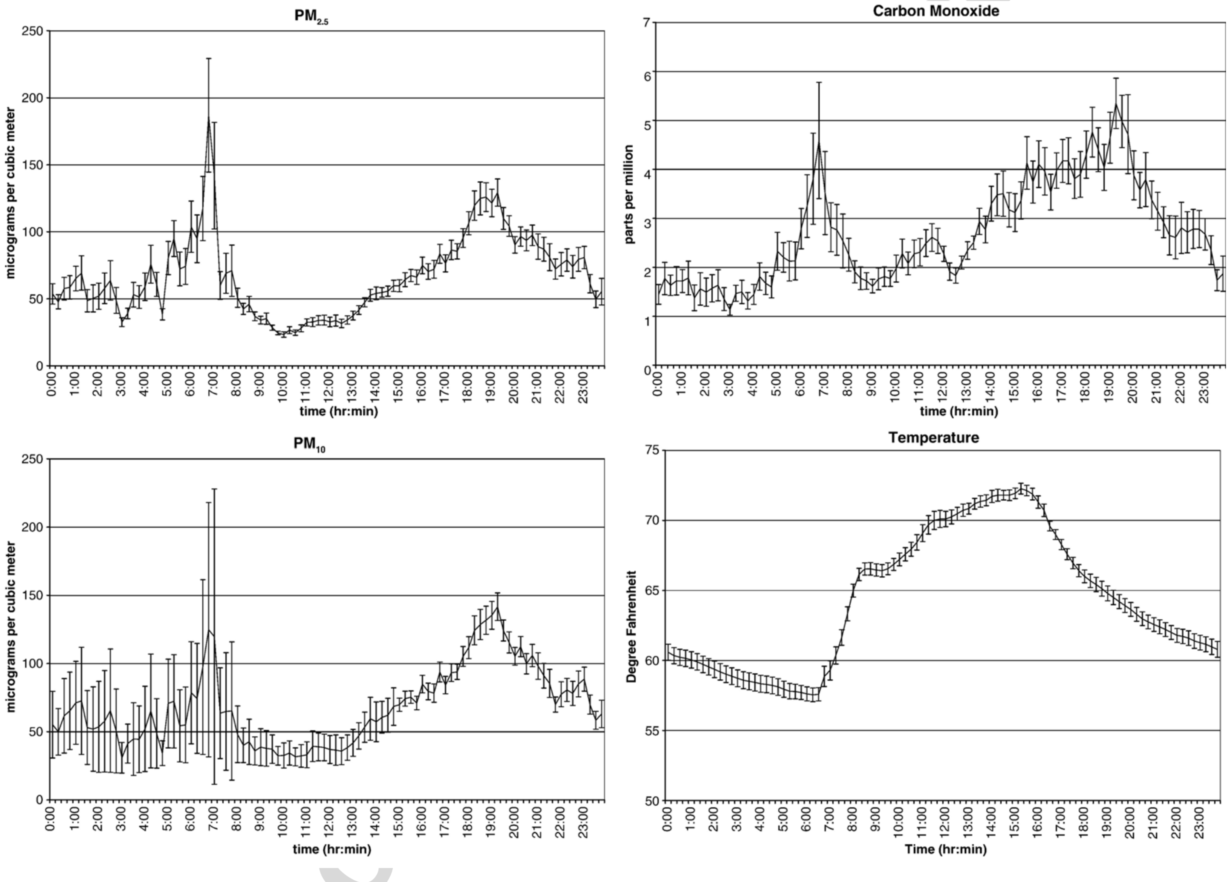

Fig. 2. 15-minute mean ± 1 standard error $PM_{2.5}$, PM_{10}, CO and temperature present at the Session Road monitoring station throughout the entire sampling period (n = 11 days).

Table 3
Statistically significant predictors of the linear mixed-effect regression models for ln(CO), ln($PM_{2.5}$) and ln(PM_{10})

Pollutant	Statistically significant predictors	Period 1			Period 2			Period 3		
		Parameter estimate	Standard error	*p*-value	Parameter estimate	Standard error	*p*-value	Parameter estimate	Standard error	*p*-value
ln(CO)	Traffic PC	No significant variables			0.179	0.084	0.048	0.204	0.089	0.034
	Any wind	−0.482	0.221	0.044	No significant variables			No significant variables		
ln($PM_{2.5}$)	Traffic PC	0.542	0.213	0.021	No significant variables			No significant variables		
ln(PM_{10})	Traffic PC	0.458	0.214	0.048	No significant variables			No significant variables		

Period 1 = early morning: 4:50–6:30 am.
Period 2 = morning rush hour: 6:30–9:10 am.
Period 3 = afternoon rush hour: 3:40–5:40 pm.

estimate = −0.482; 38% decrease with wind present; $p=0.044$) and Traffic Principal Component (Traffic PC) in both morning rush hour (parameter estimate = 0.179; 20% increase; $p=0.048$) and afternoon rush hour (parameter estimate = 0.204; 23% increase; $p=0.034$). Traffic PC was the only significant explanatory variable produced in the $PM_{2.5}$ (parameter estimate = 0.542; 72% increase; $p=0.021$) and PM_{10} (parameter estimate = 0.458; 58% increase; $p=0.048$) multiple regression models, and both occurred during the early morning monitoring period.

3.3. Average ambient concentrations at Session Road station

Table 4 shows the mean ± standard deviation, maximum and minimum 24-hour average of the pollutants measured at the Session Road station over the 11 days of sampling. Complete 24-hour DustTrak $PM_{2.5}$ and PM_{10} data were only collected on 8 of the total 11 sampling days due to equipment problems with the three days of incomplete data occurring within the first half of sampling. The average $PM_{2.5}$ and PM_{10} concentrations measured by the DustTraks during the eight days of uninterrupted sampling were 67.0 ± 28.2 and 80.1 ± 28.0, respectively. The 24-hour average gravimetric $PM_{2.5}$ during the 8 days corresponding to the DustTrak data was 67.0 ± 17.5 μg/m^3 and was 72.9 ± 21.2 μg/m^3 (max = 124.4 μg/m^3; min = 46.7 μg/m^3) during the total 11 days sampling period. CO and NO_2 concentrations throughout the entire sampling period were 2.64 ± 0.6 ppm and 27.7 ± 1.6 ppb, respectively. The 24-hour (PM and CO) and 72-hour (NO_2 and VOCs) mean concentrations of each pollutant except BTEX VOCs decreased as December 25 (last day of sampling) approached with the highest sample concentration (either 24 h or 72 h depending on the pollutant) of each pollutant occurred within the first half of the study. Toluene values are not reported due to high-variability in field blank concentrations.

Table 4
24-hour pollutant average at Session Road monitoring station over the entire sampling period

Pollutant	# of days	Unit	Average ± standard deviation	Max	Min
$PM_{2.5}$ (Harvard Impactor)	11	μg/m^3	72.9 ± 21.2	124.4	46.7
$PM_{2.5}$ (Harvard Impactor)	8	μg/m^3	67.0 ± 17.5	105.0	46.7
$PM_{2.5}$ (DustTrak)[a]	8	μg/m^3	67.0 ± 28.2	117.5	43.0
PM_{10} (DustTrak)[a]	8	μg/m^3	80.1 ± 28.0	127.9	56.8
CO	11	ppm	2.64 ± 0.6	3.6	1.4
NO_2[b]	11	ppb	27.7 ± 1.6	26.1	29.7
Benzene[b]	11	μg/m^3	8.4 ± 1.4	9.9	6.9
Ethylbenzene[b]	11	μg/m^3	4.6 ± 2.0	6.6	1.9
p-xylene[b]	11	μg/m^3	4.4 ± 1.9	6.3	1.8
m-xylene[b]	11	μg/m^3	10.2 ± 4.4	14.8	4.7
o-xylene[b]	11	μg/m^3	7.5 ± 3.2	10.8	3.4

[a] Complete 24-hour real-time data were collected for only 8 out of 11 days due to equipment problems; data from the 3 incomplete days are omitted.
[b] Samples ran for a 72-hour period.

4. Discussion

4.1. Multiple regression models and nocturnal inversions

In spite of more motor vehicle, residential and commercial activities occurring within Baguio's CBD during the day opposed to the night, the lowest one-hour average ambient $PM_{2.5}$ concentration measured at the Session Road station during the night was 75% higher than that during the day (Fig. 2). This difference in ambient concentrations is most likely due to the presence of nocturnal inversions often present within Baguio due to its location within a mountain basin. Inversions prevent the vertical mixing of air during the night therefore increasing air stagnation resulting in the production of a "blanket" of air pollution in the lower atmosphere. Morning PM was shown to greatly increase just after sunrise when the pollution blanket was broken up by the sun and returned to ground-level as indicated in the increase of temperature and PM concentrations starting at 6:30 am in Fig. 2.

Due to nocturnal inversions and varying pollution sources throughout the day making each sampling period unique, individual models were formulated for each sampling period opposed to one model containing all the data merged from the three sampling periods. Within the $PM_{2.5}$ and PM_{10} multiple regression models traffic intensity was the only significant explanatory variable and was only significant in the early morning sampling period. During this time period the limited vertical mixing of the lower atmosphere due to the nocturnal inversion created a scenario in which air pollution dispersed poorly allowing the PM to remain present for longer periods of time. The scarcity of commercial pollution emissions within the CBD during the 4:30–6:30 am monitoring period created a scenario in which motor vehicle emissions could comprise a larger percentage of street-level $PM_{2.5}$ and PM_{10}. Secondly, the presence of wind had a significantly negative association with early morning CO concentrations because increased wind speeds would result in increased horizontal CO dispersion rates.

Although motor vehicle densities were highest during the rush hour periods, other pollution sources were present (e.g. street vendors and restaurants/bakeries) contributing to the overall pollution. During the morning rush hour period (6:30–9:10 am) Baguio's CBD was heavily influenced by the remnants of the inversion's "pollution blanket" as it returned to the ground in heavy, visible sheets as well as few commercial and residential point sources. The afternoon rush hour period (3:40–5:40 pm) was similar to the morning rush hour except all commercial businesses were open and the vertical mixing of the lower atmosphere was expected to be at its highest rate. Non-automotive pollution sources were not found to be significant during the rush hours potentially due to the inability to adequately quantify pollution sources such as the inversion blanket and those originating from within buildings.

4.2. Ambient pollution concentrations

The results of this study indicate that air pollution levels, particularly PM, in Baguio City are potentially elevated and therefore may merit public health concern. Since there are no Filipino $PM_{2.5}$ ambient standards, the US National Ambient Air Quality Standards (NAAQS) will be used for comparison. The mean 24-hour $PM_{2.5}$ concentration measured at the Session Road fixed monitoring site (72.9 μg/m^3; $n=11$ 24-hour samples) was higher than the NAAQS annual (15 μg/m^3) and 24-hour (65 μg/m^3) standards present in the US (US CFR, 1997). Although the sampling period was not long enough to declare the area out of compliance, the concentrations present, if sustained for a long enough period of time, would result in a violation of these standards. With all five of the eleven sampling days over the 24-hour limit (65 μg/m^3) occurring within the first half of the study (Dec. 14–19), the negative trend indicated that pollution concentrations were decreasing as the religious and political holiday season (Christmas) approached. This decrease is believed to be due to less automotive traffic within the CBD because of increased leave from work and the closings of the schools and colleges within the CBD for the holiday season. The mean 24-hour CO (2.64 ppm) and NO_2 (27.7 ppb) concentrations measured at the Session Road fixed monitoring site were below established Philippine (24-hour $NO_2=0.08$ ppm; 8-hour CO=9 ppm; 1-hour CO=31 ppm) and US (annual $NO_2=0.053$ ppm; 8-hour

Table 5
Mean $PM_{2.5}$ concentrations measured in various urban, ambient air pollution studies throughout the world

Citation	Sampling period	Sampling location	$PM_{2.5}\pm1$ standard deviation (μg/m^3)
Yang et al. (2005)	July 1999–June 2000	Beijing, China	116.0
Chan et al. (2005)	August 2003	Beijing, China	93.6
This study	December 2004	Baguio City, Philippines	72.9±21.2
Kang et al. (2004)	April 2001–February 2002	Seoul, South Korea	48.5
Götschi et al. (2005)	June 2000–December 2001	Turin, Italy	44.9±22.5
Shendell and Naeher (2002)	May–June 1997	Guatemala City, Guatemala	37.9±21.5
Cassidy et al. (in review)	July–August 2003	Trujillo, Peru	36.1±9.2
Chow et al. (2002)	February–March 1997	Mexico City, Mexico	38.7
USEPA (2005)	January 2002–December 2004	Los Angeles-South Coast Air Basin	24.8
Götschi et al. (2005)	June 2000–December 2001	Barcelona, Spain	22.2±7.6
Götschi et al. (2005)	June 2000–December 2001	Paris, France	17.8±6.9
Götschi et al. (2005)	June 2000–December 2001	Reykjavik, Iceland	3.7±1.7

CO = 9 ppm; 1-hour CO = 35 ppm) air pollution standards indicating that these levels are unlikely to lead to adverse health outcomes within the general population.

Table 5 compares the ambient concentrations measured in this study to urban, ambient $PM_{2.5}$ concentrations seen in other studies from around the world. Excluding the studies in Beijing, China no study observed an average ambient $PM_{2.5}$ concentration as high as the levels present in Baguio City. Even the Los Angeles-South Coast Air Basin, which had the highest 2002–2004 average ambient $PM_{2.5}$ of all areas within the United States, had a mean $PM_{2.5}$ concentration 1/3 of that measured in Baguio City. Continuous ambient concentrations of the magnitude seen in Baguio are rarely seen in developed countries and sporadically seen within developing countries except in areas prone to elevated pollution concentrations partially due to local topography. The combination of pollution sources and the local topography make Baguio City's ambient air quality worse than that seen in most locations throughout the world.

In 2003 there were a total of 22,713 vehicles registered in Baguio City (Department of Transportation and Communication, 2003). Of these cars 61% run on diesel fuel, and the majority of the motor vehicles present within the CBD, primarily taxis and jitneys, use diesel. In addition to the fact that the ambient and street-level concentrations potentially exceed pollution standards, the fact that diesel fuel emissions comprise a large percentage of the ambient pollution in Baguio's CBD makes the scenario more threatening. Studies have shown that diesel exhaust particles are often more toxic than those from other combustion processes resulting in increased exacerbation of negative health effects (Bremner et al., 1999; Brunekreef et al., 1997; Hoek et al., 2000; Van Vliet et al., 1997).

With three elementary/high schools, two technical schools and four colleges within Baguio's CBD there is a regular presence of children, teenagers and young adults within the area. The average pedestrian count during the monitoring periods of the 30 street sites was 29.0 people per sidewalk per minute (max of 146 people per minute), several of which were young children. Van Vliet et al. (1997) studied whether motor vehicle exhaust had an effect on respiratory health of children who attended schools within 1000 m of a major roadway and found that traffic density of the closest roadway and the amount of time the school was downwind of the roadway were significant predictors of black smoke concentrations, an indicator for diesel emissions, in the schools. The study derived that long-term exposures to traffic-related air pollution, in particular diesel exhaust particles, may increase multiple chronic respiratory symptoms especially in girls. A separate study performed by the University of the Philippines measured the impact of vehicular emissions on vulnerable populations in Metro Manila in 1990–1991 and 1994 found that the prevalence of respiratory symptoms among school children and children who work as street vendors ranged from 4.8 to 27.5% and 15.8 to 40.6%, respectively (Subida and Torres, 1994).

4.3. Limitations

The limitations of this study primarily stem from the short sampling time. Since ambient sampling took place over 11 days, this study could not address seasonal effects making it difficult to determine if the ambient concentrations measured were representative of the annual average. With historic air pollution data outside of TSP lacking, it is hard to determine how pollution concentrations fluctuate throughout the year. However, the study took place during the city's dry season (October to May) when rain, which removes PM from the atmosphere, is scarce. Since the study occurred during the dry season and in winter when temperature inversions are likely to be stronger, the pollution concentrations measured may be greater than those during the warmer, wetter season. However, air pollution concentrations were declining during the second half of sampling period potentially due to a holiday effect which would lower the average concentrations measured in comparison to a time that saw no such effect.

Secondly, the use of DustTraks in a variety of settings created a limiting factor. All of the DustTraks were adjusted according to a concentration ratio created using the data produced by a DustTrak and two gravimetric $PM_{2.5}$ monitors collocated at the Session Road station over the 11 days of sampling. The PM measured three stories above street-level at the monitoring station may not be representative of the PM measured at various locations within the CBD therefore potentially changing the concentration ratio. Since gravimetric measurements could be not taken at the 30 street-level monitoring sites, the concentration ratio produced at the fixed monitoring station was used for all locations in the study.

Thirdly, the air currents present at the third story location of the fixed monitoring site may have been affected by the structural design of the windowsill, awning and surrounding buildings. These microair current variations may have been different at ground-level potentially affecting pollution dispersion patterns. Ideally, an additional fixed monitoring station would have been established at ground-level directly below the third-story monitors in order to correlate the ground-level and third-story diurnal pollution fluctuations, determine the vertical pollutant distribution, and investigate whether or not potential air current variations significantly altered pollutant concentration variations at the third-story level. A lack of additional monitoring equipment and equipment security issues prevented a ground-level monitoring station from being present within the CBD.

Finally, only 45 min of sampling per site was collected, most of which were during times of high pollution concentrations. Therefore, the ability to extrapolate these short samples to human exposures over long periods of time is limited. However, many health conditions associated with short-term PM exposures such as reduced breathing capacity can be seen within minutes thus making these "worst case" samples important in relation to acute exposures.

5. Conclusions

The data suggest that ambient $PM_{2.5}$ levels in Baguio City, Philippines are potentially above the US EPA daily (65 μg/m^3) and annual ambient standards (15 μg/m^3) and as such warrant public health concern. Further, the data suggests that nocturnal inversions play a large role in the night and early morning's PM concentrations within the CBD by limiting the vertical mixing of the lower atmosphere and preventing the dilution of PM and CO. The use of environmental observational variables in predicting PM and CO concentrations indicated that traffic-related variables and the presence of wind were the most representative environmental observational variables.

Future research in Baguio City, Philippines is necessary to determine seasonal variation of ambient pollution as well as measuring personal exposures of air pollution to tourists and citizens. With over one-half million people visiting Baguio annually and multiple schools located in Baguio's CBD, pollution concentrations of the magnitude seen in this study should be further investigated. Additionally, the presence of air pollution within Baguio City may pose potential economic implications for the city where tourist-related income plays an important role in the local economy.

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References

Akers MA, Sowell RL. A conceptual model for planning and designing healthy urban landscapes in the Third World: a study of street vendors in the Philippines. Landsc Rev 2004;9(1):45–9.

ATSDR. Toxicological profile for benzene. Public Health Service, Atlanta, GA: U.S. Department of Health and Human services; 1997.

Baguio Department of Transportation and Communication. Comparative City Socio-Economic Situationer; 2002–2003.

Bremner SA, Anderson HR, Atkinson RW, McMichael AJ, Strachan DP, Blank JM, et al. Short term associations between outdoor air pollution and mortality in London 1992–1994. Occup Environ Med 1999;56:237–44.

Brown R. Monitoring the ambient environment with diffusive samplers: theory and practical considerations. J Environ Monit 2000;2:1–9.

Brown VM, Crump DR. Diffusion sampling of volatile organic compounds in ambient air. Environ Monit Assess 1998;52:43–55.

Brown VM, Crump DR, Gardiner D, Yu CWF. Long term diffusive sampling of volatile organic compounds in indoor air. Environ Technol 1993;14:771–7.

Brunekreef B, Janssen NAH, de Hartog J, Harssema H, Knape M, van Vliet P. Air pollution from truck traffic and lung function in children living near motorways. Epidemiology 1997;8:298–303.

Cassidy BE, Aguilar MV, Naeher LP. Street-level and ambient reduction of particulate matter and carbon monoxide in Trujillo, Peru on *El Dia Sin Autos* ("The Day Without Cars") J Environ Health. in review.

Chan CY, Xu XD, Li YS, Wong KH, Ding GA, Chan LY, et al. Characteristics of vertical profiles and sources of PM2.5, PM10 and carbonaceous species in Beijing. Atmos Environ 2005;39: 5113–24.

Chow JC, Watson JG, Edgerton SA, Vega E. Chemical composition of $PM_{2.5}$ and PM_{10} in Mexico City during winter 1997. Sci Total Environ 2002;287(3):177–201.

Department of Transportation and Communications of Baguio City, Philippines. 2002–2003 comparative city socio-economic situationer; 2003.

Dockery DW, Pope CA, Xu III, Spengler X, Ware JD, Fay JH, et al. An association between air pollution and mortality in six U.S. cities. N Engl J Med 1993;329N:1753–9.

Götschi T, Arx MEH, Heinrich J, Bono R, Burney P, Forsberg B, et al. Elemental composition and reflectance of ambient fine particles at 21 European locations. Atmos Environ 2005;39:5947–58.

Harrell FE. Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis. New York: Springer; 2001.

Hassan MN, Zainal A, Yusoff MK, Ghazali AW, Muda A, Zakaria MP. Damage costs of the 1991 and 1994 haze episodes in Malaysia. Paper read at Climate and Life in the Asia Pacific, April 10–13, 1995, Brunei Darussalam; 1995.

Health Effects Institute (HEI). Airborne particles and health: HEI epidemiologic evidence; 2001.

Hoek G, Brunekreef B, Verhoeff A, van Wijnen J, Fisher P. Daily mortality and air pollution in the Netherlands. J Air Waste Manag Assoc 2000;50:1380–9.

Hoekman SK. Speciated measurements and calculated reactivities of vehicle exhaust emissions from conventional and reformulated gasolines. Environ Sci Technol 1992;26(6):1206–16.

Kang CM, Sunwoo Y, Lee HS, Kang BW, Lee SK. Atmospheric concentrations of PM2.5 trace elements in the Seoul urban area of South Korea. J Air Waste Manag Assoc 2004;54(4):432–9.

Khatree R, Naik DN. Multivariate data reduction and discrimination with SAS software. Cary NC: SAS Institute Inc.; 2000.

Koistinen K, Kousa A, Virpi T, Hanninen O, Jantunen M. Fine particulate (PM2.5) measurement methodology, quality assurance procedures, and pilot results of the EXPOLIS study. J Air Waste Manage Assoc 1999;49:1212–20.

Naeher LP, Brauer M, Lipsett M, Zelikoff JT, Simpson CD, Koenig JQ, Smith KR. Woodsmoke health effects: a review. Inhal Toxicol 2007;19:67–106.

Palmes ED, Gunnison FF, DiMattio J, Tomczyk C. Personal sampler for nitrogen dioxide. Am Ind Hyg Assoc J 1976;37:570–7.

Reinhardt TE, Ottmar RD, Castilla C. Smoke impacts from agricultural burning in a rural Brazilian town. J Air Waste Manage Assoc 2001;51(3):443–50.

Republic of the Philippines Department of Environment and Natural Resources. 2002 National Air Quality Status Report. Quezon City; 2003.

Rubin DB. Multiple imputation for nonresponse in surveys. New York: John Wiley & Sons, Inc.; 1987.

Schafer JL. Analysis of incomplete multivariate data. New York: Chapman and Hall; 1997.

Schenker N, Taylor JMG. Partially parametric techniques for multiple imputation. Comput Stat Data Anal 1996;22:425–46.

Shendell DG, Naeher LP. A pilot study to assess ground-level ambient air concentrations of fine particles and carbon monoxide in urban Guatemala. Environ Int 2002;28(5):375–82.

South Coast Air Quality Management District. Multiple Air Toxics Exposure Study (MATES-II) final report; 2000.

Subida RD, Torres EB. Impact of vehicular emissions on vulnerable populations in Metro Manila. Manila: World Health Organization/ College of Public Health University of the Philippines; 1994.

U.S. Code of Federal Regulations. U.S. CFR Title 40; Part 50. National Primary and Secondary Ambient Air Quality Standards. 1997.

USEPA. United States Environmental Protection Agency. Quality Assurance Guidance Document; Method Compendium; Field Standard Operating Procedures for the PM2.5 Performance Evaluation Program. United States Environmental Protection Agency Office of Air Quality Planning and Standards; 1998, Nov.

USEPA, United States Environmental Protection Agency. PM2.5 air quality data update 2002–2004. U.S. EPA's Air Quality System (AQS); 2005.

Van Vliet P, Knape M, de Hartog J, Janssen N, Harssema H, Brunekreef B. Motor vehicle exhaust and chronic respiratory symptoms in children living near freeways. Environ Res 1997;74:122–32.

World Bank. Philippines Environment Monitor 2002.

World Health Organization (WHO). Air quality guidelines for Europe. Second Edition. Regional Office for Europe; 2000.

World Health Organization (WHO). Asia's cities face disease crisis, WHO warns; 2005. Regional Office for the Western Pacific <www.wpro.who.int/media_centre/press_releases/pr_20031014.htm>.

WOWPhilippines. "Baguio City — summer capital of the Philippines"; 2005, 15 Nov. http://www.tourism.gov.ph/explore_phil/place_details.asp?content=description&province=105.

Yang F, He K, Ma Y, Zhang Q. Characterization of carbonaceous species of ambient PM2.5 in Beijing, China. J Air Waste Manage Assoc 2005;55:984–92.