AMBIENT AND STREET-LEVEL AIR POLLUTION STUDIES WITHIN TRUJILLO, PERU AND BAGUIO CITY, PHILIPPINES

by

BRANDON EDWARD CASSIDY

(Under the Direction of LUKE NAEHER)

ABSTRACT

Air pollution studies in Trujillo, Peru (July-August and October-November 2003) and Baguio City, Philippines (December 2003) were conducted to quantify the concentrations of multiple air pollutants. Ambient concentrations of particulate matter ≤2.5μm in aerodynamic diameter ($PM_{2.5}$), carbon monoxide (CO), nitrogen dioxide (NO_2) and select volatile organic compounds (VOCs) were collected in Peru and Philippines as well as street-level concentrations of $PM_{2.5}$, PM_{10} and CO in downtown Baguio City. Multiple regression modeling was done with Filipino street-level pollutant concentrations and environmental variables including traffic intensity, road size, wind, non-automobile pollution sources, building stories and terrain. Traffic intensity was significant with pre-morning rush hour (4:50-6:30am) $PM_{2.5}$ and PM_{10} while significant with CO in both morning and afternoon rush hours. Street-level $PM_{2.5}$ concentrations in Trujillo, Peru is reduced 50% when automobile traffic is removed. Ambient pollution concentrations in both studies were above established $PM_{2.5}$ limits.

INDEX WORDS: $PM_{2.5}$, PM_{10}, CO, NO_2, VOC, Ambient, Street-level, Traffic, Air pollution, Meteorology, Regression model

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December 2005

DEDICATION

I would like to dedicate this thesis to my family—especially my parents, my grandparents, my sister and my Uncle Rick—for their never-ending support and encouragement throughout my entire life. I would like to specially dedicate this thesis to my hero and late cousin, Christopher Rogers, who taught me how to live my life the best that I can even when I don't know what tomorrow may bring. Most importantly I would also like to dedicate this thesis to my Lord, Jesus Christ, for His never ending gift of love and support as well as his continuous help through my times of strife. Only through His love and the love of my family have I realized that even when things may seem their worst there will always be hope and love as long as you know where to look.

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CHAPTER 1

INTRODUCTION

Chapter 1 outlines the information presented in each chapter. Chapter 2 presents an overview of relevant literature related to the air pollution projects completed during the author's graduate studies. Chapter 3 contains a manuscript submitted for publication in the Journal of Air and Waste Management (JAWMA) in November 2005. This study describes the ambient air pollution concentrations measured in Trujillo, Peru between July-August and October-November, 2003 at an urban and a rural rooftop, fixed-site monitoring station. In addition to the urban and rural monitoring stations, continuous street-level sampling of particulate matter $\leq$2.5 µm aerodynamic diameter ($PM_{2.5}$) took place in July 2003 over 20 days in downtown Trujillo including one day where no automobiles were allowed within the downtown area. Chapter 4 contains a manuscript that will be submitted for publication in Environmental Health Perspectives in December 2005. This chapter describes a study that took place in Baguio City, Philippines in December 2004 measuring ambient and street-level pollution concentrations. Street-level measurements were taken at 30 sites within downtown Baguio over three periods including an early morning (4:50-6:30am), a morning rush hour (6:30-9:10am) and an afternoon rush hour (3:50-5:40pm) period. Multiple regression models were formed for various street-level pollutants using environmental characteristics collected during each sampling. Chapter 5 contains conclusions based on the findings of the previous chapters and a comparison of Trujillo and Baguio City ambient concentrations to ambient concentrations present at different locations throughout the world.

CHAPTER 2

SELECTED LITERATURE REVIEW OF AIR POLLUTION AND AMBIENT AIR POLLUTION SAMPLING

Air pollution health effects in the developing world

Air pollution is a major environmental health problem that affects both developed and developing nations. Air pollution originates from the combustion of fossil fuels in either a natural or anthropogenic process. The combustion of fossil fuels result in the release of a variety of chemicals that may either directly or indirectly affect environmental and human health. Air pollution includes a mixture of pollutants at various concentrations including but not limited to particulate matter (PM), carbon monoxide (CO), sulfur oxides (SOx), nitrogen oxides (NOx), ozone (O_3), lead (Pb), volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) (US CFR, 1997).

The ever increasing scientific literature pertaining to air pollution and its associated health effects has increased awareness and concern throughout the populations. Over the years epidemiological studies have shown a correlation between increases in exposure to air pollution and increases in morbidity and mortality, particularly among those with preexisting respiratory and/or cardiovascular disease. Examples of associated morbidity include asthma, chronic obstructive pulmonary disease, cardiovascular disease, lower birth weights, cancer, and premature births (ATSDR, 1997; ATSDR, 2000; Dockery, 1993; HEI, 2001; WHO, 2000).

Although air pollution affects everyone regardless of socioeconomic status, the magnitude of air pollution exposures is higher within the developing world (WHO, 2002) where regulation and enforcement may be difficult. The increasing industrial, commercial and residential activities as well as the presence of motor vehicles within developing countries have led to higher ambient air pollution concentrations and their

associated human health impacts (UNEP, 2000). The extent of current scientific literature on ambient air pollution in developing countries is relatively lacking when compared to the numerous studies that have taken place in developed countries. However, there is a steadily growing collection of studies showing a strong correlation between exposure to ambient air pollution and negative health effects in the developing world (Cohen et. al, 2005; HEI, 2004; Romieu et. al, 2002; WHO, 2002; WHO, 2004).

Impoverished areas, such as those often seen within developing countries, are often dominated by outdated technologies and practices. These areas are limited in their ability to integrate these newer technologies into their infrastructure due to financial hardships. The use of older equipment often results in a higher production rate of undesired byproducts including air pollution. Increased concentrations of ambient air pollution pose a potential health risk to susceptible individuals including fetuses, neonates, elderly, immunocompromised and the malnourished. Also, many of the residents within these potentially at-risk areas are undernourished, therefore making them more susceptible than healthy populations (WHO, 2000; WHO, 2002).

The World Health Organization (WHO) estimates that 1.5 billion urban dwellers live in areas with levels of outdoor air pollution above the WHO ambient air pollution guidelines. About a half a million deaths worldwide are due to particulate matter (PM) and sulfur dioxide in outdoor air (WHO, 2005).

Air pollution sampling methods

Accurately determining the magnitude and source of personal exposure to air pollution is a daunting task. People are continuously being exposed to air pollution in a

variety of environments throughout their daily activities. Personal exposure to air pollution and the resulting prevalence of negative health effects depend on the exposure duration, frequency and magnitude of (1) ambient air pollution, (2) indoor air pollution concentrations and (3) personal activity patterns. Personal activity patterns often play a significant role in one's exposure and can include activities such as smoking, cooking and commuting habits.

In order to adequately determine one's exposure, 24-hour personal sampling would be necessary. This process, especially when dealing with a large subject population within a study, can be time-consuming, expensive and bothersome to the subject wearing the equipment. A secondary option includes placing monitors in locations frequented by the subject. However, time-activity-diaries and questionnaires are required in order to determine the subject's location and duration spent in respect to the multiple monitors. This method, however often less bothersome to the subject, is overly dependent on the subjects to adequately record their activities and locations and therefore may lead to inaccurate results if the subjects wrongly interpret or partially complete the time-activity-diary. A third option is fixed-site monitoring stations.

Fixed-site monitoring stations are non-mobile, outdoor locations equipped with monitors that continuously measure air pollution concentrations in the ambient environment. Fixed-site monitoring stations have been used for years to determine the ambient pollution concentrations present in large geographical areas. They are cheap, require low maintenance compared to personal sampling, and the data can be extrapolated for personal exposure of the local inhabitants. Fixed-site air monitoring has been previously used in epidemiological studies as a proxy for personal exposure (Beeson

et al., 1998; Boudet et al., 2001; Katsouyanni et al., 1995; Pope et al., 1995; Sajani et al., 2004). However, fixed-site monitoring stations relatively poor proxies due tot heir inability to adequately quantify indoor exposures or individual personal habits. However, their cost and ease make them useful tools in determining ambient pollution exposure and ambient pollution concentrations in different locations.

Ambient air pollution standards

In the United States ambient air pollution limits for common pollutants known as "criteria pollutants" have been established by the Environmental Protection Agency (EPA). These ambient pollution standards, known as the National Ambient Air Quality Standards (NAAQS) were originally established in 1970 via the Clean Air Act and have been amended over time. The EPA has set NAAQS for these six criteria pollutants, including carbon monoxide, lead, nitrogen dioxide, particulate matter (including both particles under 2.5 μm and 10 μm in aerodynamic diameter), ozone and sulfur oxides (US CFR, 1997) (Table 2-1).

Although several countries have standards based upon or similar to the US NAAQS, the NAAQS themselves have no jurisdiction outside of the United States. A similar set of ambient air pollution staandards are the WHO Air Quality Guidelines (Table 2-2). Since the WHO does not have any governmental jurisdiction, their ambient air pollution limits are suggestive guidelines. However, the WHO guidelines are more inclusive than the US NAAQS including the 16 organic pollutants, 12 inorganic pollutants, 4 classical pollutants including PM, CO, NO_2, SO_2 and 3 indoor air pollutants (WHO, 2000).

Within the developing world, in-country research on the relationship between health effects and ambient air pollution concentrations is often lacking, therefore making developing countries reliant upon other's research in order to set their ambient standards. Within countries such as Peru and the Philippines, ambient pollution limits similar to the NAAQS and WHO Air Quality Guidelines have been established. However, these countries, as well as many other developing and developed countries, are having problems complying with these standards (WHO, 2002)

Motor vehicles in the developing world

Motor vehicles often constitute a major ambient air pollution source, particularly within the developing world where motor vehicles are often older and poorly maintained. Cities in the developing countries of Latin America and Southeast Asia often have large motor vehicle fleets that contribute to the total urban pollution. Older and/or poorly maintained motor vehicles have an increased emission output per unit vehicle compared to newer and better-maintained automobiles (WHO/UNEP, 1992).

Previous studies have attributed a large percentage of total fine particles ($\leq$ 2.5 µm in diameter) in ambient air to vehicles, including 66.5% in Athens, Greece (Economopoulou and Economopoulous, 2002), 82% in Malaysia (Afroz et al., 2003), 70% in Buenos Aires (PAHO, 1998) and 70% in Mexico City (INEGI, 1998). In addition to particulate matter, VOCs (particularly 1,3-butadiene and benzene) account for 68% of the cancer risk from all vehicle-related pollutants while $PM_{2.5}$ only accounts for 28% (US EPA, 1995).

The development of catalytic converters, PM traps and unleaded fuels have led to a marked reduction in gaseous and PM vehicular emissions. However, these devices may prove too expensive in lower income areas, especially within developing countries. Unleaded fuels normally contain more aromatic constituents than leaded fuels, which elevate VOC exhaust emissions if vehicles are not fitted with catalytic converters (Hoekman, 1992; Kaiser et al., 1992; Koehl et al., 1991; Perry and Gee, 1995; Westerholm et al., 1988).

Objectives of research

The purpose of the research addressed in Chapter 3 was to determine seasonal ambient concentrations of $PM_{2.5}$, CO, NO_2 and select VOCs at a rural and an urban monitoring station in July-August and October-November 2003 in Trujillo, Peru, a city of 732,600 people. In addition to the ambient rooftop fixed-site monitoring stations within Trujillo, a secondary fixed-site was temporarily established for 20 days in July-August in order to collect continuous street-level $PM_{2.5}$ adjacent to downtown Trujillo's automotive-dense streets. Further, a unique natural experiment took place on July 15, 2003 where no motor traffic was allowed within the downtown area of Trujillo. A real-time aerosol monitor was established at street level to determine the $PM_{2.5}$ concentrations present during periods without motor traffic (July 15, 2003) and with motor traffic (following 19 days).

The purpose of the research addressed in Chapter 4 was to determine ambient and street-level air pollution concentrations in downtown Baguio City, Philippines, a mountainous city of 250,000 people known as "The Summer Capital of the Philippines".

Ambient concentrations of $PM_{2.5}$, PM_{10}, CO, NO_2 and select VOCs were measured at a fixed-site monitoring station within downtown Baguio City. Street-level $PM_{2.5}$, PM_{10} and CO concentrations were measured for 15-minutes apiece during three time periods—early morning (4:50-6:30am), morning rush hour (6:30-9:10am) and afternoon rush hour (3:40-5:40pm). Multiple regression modeling was done using the average 15-minute pollutant concentrations and environmental characteristics specific to each site.

Both Chapter 3 and Chapter 4 illustrate a common problem occurring at two unrelated cities a half a world apart. Both of these cities are suffering from the same problem—air pollution. From the preliminary information it was hypothesized that Trujillo, Peru would be suffering from high ambient particulate matter and VOC concentrations due to the relatively non-existence of catalytic converters in an unleaded fuel-using country. It was also hypothesized that ambient particulate matter concentrations in the downtown area would be elevated in Baguio City, Philippines because over half of all registered vehicles use diesel fuel and the combustion of diesel fuel releases large amounts of particulate matter into the atmosphere.

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Table 2-1. United States National Ambient Air Quality Standards.		
POLLUTANT	**AVERAGING TIME**	**US National Ambient Air Quality Standards[+]**
Carbon Monoxide	1-hour	35 ppm (40 mg/m^3)
	8-hours	9 ppm (10 mg/m^3)
Lead	Quarterly	1.5 µm/m3
Nitrogen dioxide	24-hour	N/A
	1-year	0.053 ppm (100 µm/m^3)
PM_{10}	24-hour	150 µm/m^3
	1-year	50 µm/m^3
$PM_{2.5}$	24-hour	65 µm/m^3
	1-year	15 µm/m^3
Ozone	1-hour	0.12 ppm
	8-hours	0.08 ppm
Sulfur Oxides	24-hour	0.14 ppm
	1-year	0.03 ppm

Figure 2-2. World Health Organization Ambient Air Guidelines		
Substance	**Time-weighted average**	**Averaging Time**
Cadmium	5 ng/m^3	annual
Carbon disulfide	100 µg/m^3	24 hours
Carbon monoxide	100 mg/m^3	15 minutes
	60 mg/m^3	30 minutes
	30 mg/m^3	1 hour
	10 mg/m^3	8 hours
1,2-Dichloroethane	0.7 mg/m^3	24 hours
Dichloromethane	3 mg/m^3	24 hours
	0.45 mg/m^3	1 week
Formaldehyde	0.1 mg/m^3	30 minutes
Hydrogen sulfide	150 µg/m^3	24 hours
Lead	0.5 g/m^3	annual
Manganese	0.15 µg/m^3	annual
Mercury	1 µg/m^3	annual
Nitrogen dioxide	200 µg/m^3	1 hour
	40 µg/m^3	annual
Ozone	120 µg/m^3	8 hours
Particulate matter	Dose-response	
Styrene	0.26 mg/m^3	1 week
Sulfur dioxide	500 µg/m^3	10 minutes
	125 µg/m^3	24 hours
	50 µg/m^3	annual
Tetrachloroethylene	0.25 mg/m^3	annual
Toluene	0.26 mg/m^3	1 week
Vanadium	1 µg/m^3	24 hours

CHAPTER 3

$PM_{2.5}$, CO, NO_2, AND SELECT VOCs AT FIXED MONITORING STATIONS IN URBAN AND RURAL TRUJILLO, PERU DURING PERIODS OF VARYING TRAFFIC DENSITIES[1]

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[1]Cassidy, B.E.; Aguilar-Villalobos, M; Ryan, P.B.; Bayer, C.W.; Naeher, L.P. 2005. Submitted for publication to Journal of Air and Waste Management Association in November 2005

Abstract

Ambient concentrations of particulate matter ≤2.5 μm in aerodynamic diameter ($PM_{2.5}$), carbon monoxide (CO), nitrogen dioxide (NO_2) and select volatile organic compounds (VOCs) were measured at a rural and an urban monitoring station in July-August and October-November 2003 in Trujillo, Peru, a city of 732,000 people. The urban station was located atop City Hall (CH) in downtown Trujillo. The rural station was located nine kilometers west/northwest of CH at the Trujillo airport (TA). Each monitoring station was equipped with a DustTrak aerosol monitor for real-time $PM_{2.5}$, Langan for real-time CO, Tenax tubes for VOCs, Palmes Tubes for NO_2 and a SKC pump with either a BGI triplex or KTL cyclone for gravimetric $PM_{2.5}$. In addition, street-level real-time $PM_{2.5}$ was measured in downtown Trujillo during normal traffic conditions (July 16-August 4) and on July 15 when automobiles were temporarily banned from the downtown area from 8AM-6PM. The majority of air pollution levels at CH were significantly higher than TA in both seasons and significantly higher during July-August versus October-November. The 24-hr pollutant means across both seasons at CH and TA were: $PM_{2.5}$—31.3 and 28.3 μg/m^3; NO_2—9.6 and 1.2 ppb; CO—0.64 and 0.35 ppm, benzene—5.0 and 2.6 μg/m^3; toluene—26.7 and 13.5 μg/m^3; ethylbenzene—3.5 and 2.0 μg/m^3; p-xylene—6.8 and 4.8 μg/m^3; o-xylene—12.1 and 8.0 μg/m^3; m-xylene—2.5 and 1.6 μg/m^3, respectively. Mean street-level $PM_{2.5}$ from 8AM-6PM on July 15 (without traffic) was 54 μg/m^3 and 106 μg/m^3 from July 16-August 4 (with traffic). The data suggest that ambient $PM_{2.5}$ levels in downtown Trujillo likely exceed annual (15 μm/m^3)

and potentially exceed daily (65 µm/m^3) Peruvian and US EPA daily air quality standards, and that downtown Trujillo street-level $PM_{2.5}$ is reduced 50% when automobile traffic is removed.

Introduction

Approximately three-quarters of the population of Latin America live in cities. The increasing industrial, commercial and residential activities corresponding to the growing urban populations have led to rising ambient air pollution concentrations—particularly carbon monoxide (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), particulate matter (PM), tropospheric ozone (O_3), and hydrocarbons—and their associated human health impacts (UNEP, 2000).

Cities in Latin America often have large motor vehicle populations that contribute to the total urban pollution. Motor vehicles in developing countries are often older and are poorly maintained, increasing the emission output per unit vehicle compared to newer and better-maintained automobiles (WHO/UNEP, 1992). The transport sector in Latin American cities is often a major source of urban air pollution – 70 percent of emissions in Buenos Aires (PAHO, 1998) and Mexico City (INEGI, 1998) are automotive-related – with industrial, commercial, agricultural and the municipal sectors also contributing to ambient air pollution.

Several emission inventories have suggested that engines and motor vehicles can be the principal contributor of fine particulate matter or $PM_{2.5}$ (particles with an aerodynamic diameter ≤2.5 µm)—to the atmosphere in urban areas. Previous studies have attributed a large percentage of fine particulate matter in urban atmospheres to motor vehicles, including 51-69% in 1982 Los Angeles (Schauer et al., 1996), 80% in

London, England (Department for Transport, 2002), 66.5% in Athens, Greece (Economopoulou and Economopoulous, 2002) and 82% in Malaysia (Afroz et al., 2003). Epidemiological studies have shown a correlation between increases in exposure to $PM_{2.5}$ and increases in morbidity and mortality, particularly among people with respiratory or cardiovascular disease (Dockery et al., 1993; HEI, 2001; WHO, 2000).

In addition to $PM_{2.5}$, motor vehicles have the potential to release VOCs into the environment. Fuel can enter the atmosphere in the form of soluble or volatile organic compounds (VOCs) via evaporation from the fuel tank and fuel lines or through incomplete oxidation during combustion (Kittelson, 1998). VOCs have the potential to contribute in the formation of photochemical smog and ground level ozone (DOE, 1993) and may pose a carcinogenic risk. Several VOCs are either suspected or known carcinogens including but not limited to 1,3-butadiene, benzene, formaldehyde and acetaldehyde. 1,3-Butadiene and benzene account for 68% of the cancer risk from all vehicle-related pollutants, whereas particulate matter accounts for only 28% (USEPA, 1995).

Developing countries are often dominated by the use of outdated equipment. The use of older equipment may result in higher production rates of undesired byproducts including air pollution. Increased air pollution concentrations pose a potential health risk, especially to susceptible individuals including fetuses, children, the elderly, the immunocompromised and the malnourished (HEI, 2001; WHO, 2002). Many of the residents within developing countries are undernourished, which may result in more detrimental health responses to pollution than those seen in healthier populations (WHO, 2002).

Fixed-site air monitoring has been used for years to determine ambient pollution concentrations present in large geographical areas. Fixed-site air monitoring has been also used in epidemiological studies as a proxy for personal exposure (Beeson et al., 1998; Boudet et al., 2001; Katsouyanni et al., 1995; Pope et al., 1995; Sajani et al., 2004). Personal exposure of pollutants depends on the exposure duration, frequency and magnitude of (1) ambient air pollution, (2) indoor air pollution concentrations and (3) personal activity patterns (e.g. smoking and commuting habits). Although fixed site monitoring stations are limited by their inability to quantify indoor exposures or individual personal habits, they are useful tools in establishing ambient pollution concentration data.

The objectives of this study were: 1) to measure ambient concentrations of $PM_{2.5}$, CO, NO_2 and select VOCs at a rural and an urban monitoring station in July-August and October-November 2003 in Trujillo, and 2) to measure street-level $PM_{2.5}$ and CO in downtown Trujillo during normal traffic conditions (July 16-August 4) and on July 15 when motor vehicles were banned from the downtown area from 8AM-6PM. There is a paucity of ambient air pollution data from mid-size Peruvian cities. In recognition of this data gap the first objective is aimed at providing ambient air quality data for Trujillo to aid Peruvian public health and environmental regulatory officials. The second objective takes advantage of a "natural experiment" that presented itself in Trujillo in July 2003 when motor vehicles were temporarily banned for one full working day from downtown Trujillo, where vehicular traffic is typically very heavy.

Methods

Study Location

Trujillo, Peru, the capital of the department of La Libertad, is a coastal city in northern Peru located just west of the foothills of the Andes Mountains. It is approximately 34 meters above sea level and is located 8ºS and 79ºW. Figure 3-1 depicts the location of Peru within South America and the location of Trujillo within Peru.

The downtown area, located within the center of the city, is in the heart of the commercial sector of Trujillo. The oval-shaped *Avenida España* makes a perimeter around the historic district within downtown Trujillo and encompasses the *Plaza de Armas* and the neighboring street blocks (Figure 3-2). The *Plaza de Armas* is a historic one block open area adjacent to the Trujillo City Hall. On average 142,000 people visit Trujillo's historic district daily (Universidad Nacional de Trujillo, 2003). A large motor vehicle fleet, particularly taxis using unleaded gasoline, operates at all times along the two- and three-story roadways within the historic downtown area. A current ordinance prohibits the entry of any bus or public transportation van (*combi*) within the interior of the *Avenida España* perimeter, indirectly forbidding diesel-using commercial vehicles from entering the downtown area. In 2000, a large percentage of Trujillo's registered motor vehicle fleet of 53,614 units were not equipped with any emission control system and 80% of the public transportation vehicles were more than 30 years old (Trujillo City Hall, unpublished records, 2002; Trujillo Public Transportation Union, unpublished records, 2002). Potential air pollution sources in and around Trujillo include emissions from motor vehicles, sugar cane field burning (field location in relation to residential

areas and wind patterns are key in downwind exposure), and industrial, commercial, and residential pollution sources.

In 2000 Trujillo had a population of 732,600, and 33.5% of the population was 14 years of age or less (Turkstra, 2003). In the last 30 years, the population of Trujillo has doubled leading to an unplanned urban growth rate and rapid change in land use. Continued urban growth under budgetary constraints and prevalent poverty conditions (52% below the poverty line) make urban planning and other basic services to a large extent ineffective and at a sub-standard level (Turkstra, 2003).

Climate

The cold Humboldt Current running alongside the Peruvian coast and the Andes Mountains east of Trujillo (Figure 3-3) heavily influence Trujillo's moderately constant arid climate which receives an average of 4.8cm of precipitation per year. Trujillo has an average high of 78ºF during the warm season (December through March) and an average high of 68ºF and lows in the upper 50s during the cooler season (June through September). Due to Trujillo's proximity to the Pacific Ocean and the Humboldt Current, Trujillo receives a constant influx of ocean air primarily from the south/southeast that aids in the dilution of air pollutants within the city.

Trujillo airport employees collected meteorological data on each hour from 6AM to 9PM at the airport. Meteorological data included temperature, dew point, relative humidity, pressure, visibility, precipitation, and wind speed. All airport weather data was uploaded to the worldwide web where it was later accessed by the researchers at the end of the sampling period.

Ambient Air Monitoring Locations

Two monitoring stations were established in Trujillo to collect air pollution data in an urban and a rural environment. The first monitoring station was established on the roof of the three-story City Hall (CH) building in downtown Trujillo (Figure 3-2). From the monitoring station, the closest and farthest sections of the *Avenida España* perimeter surrounding the historic downtown area were 430 meters south and 850 meters north, respectively. The prevailing wind direction in this area is southeast to northwest.

The second air pollution monitoring station was established on the roof of the Trujillo's airport terminal (TA), a two-story building located 9 kilometers west/northwest of downtown Trujillo (Figure 3-3). The monitoring equipment was located approximately 0.4 kilometer south of the take-off/landing runway, on which an average of three commercial flights arrived and departed per day during the sampling period. The area surrounding the airport is used for agriculture, residences, chicken farms, or remains unused. Located 1.6 kilometers west/northwest of the airport is Huanchaco, a small town located alongside the Pacific Ocean with the closest residences located approximately 800 meters away from the monitoring station. Three hundred meters east/southeast of the airport is another light residential area approximately 300 meters squared in size. The Pacific Ocean is located 1.8kilometers west of the monitoring station.

Natural Experiment Air Monitoring Location

On July 15, 2003 from 8AM to 6PM no motor vehicles were allowed within the *Avenida España* perimeter for the inaugural *El Dia Sin Autos* ("The Day Without Cars")

providing a "natural experiment" in which the impact on air pollution resulting from no motor vehicles within historic, downtown Trujillo was studied.

In addition to the CH rooftop monitoring location, a second sampling site including a real-time aerosol monitor measuring $PM_{2.5}$ was established for this experiment outside of a first-story CH window precisely below the CH monitoring station on the roof. This street-level monitoring site was located 1.5 meters from the closest road adjacent to the *Plaza de Armas* and continuously sampled from July 15 to August 4, 2003.

Study Timeframe

Ambient air monitoring was done at CH and TA from July 3 to August 5 and October 27 to November 23, 2003. Air monitoring was done for the "natural experiment" (*El Dia Sin Autos* ["The Day Without Cars"]) from July 15 to August 4, 2003 with no cars present in historic, downtown Trujillo from 8AM to 6PM on July 15.

Pollutants Measured and Equipment Description

Real-time and time-integrated $PM_{2.5}$, real-time CO, time-integrated NO_2 and time-integrated select VOCs (BTEX: benzene, toluene, ethylbenzene and xylene) were measured at the CH and TA monitoring stations. In addition to the real-time $PM_{2.5}$ and CO collected atop CH that was used for the "natural experiment" study (*El Dia Sin Autos* ["The Day Without Cars"]), real-time, street-level $PM_{2.5}$ was also measured outside CH.

$PM_{2.5}$ concentrations were measured with real-time and time-integrated instruments. Twenty-four-hour time-integrated $PM_{2.5}$ samples were collected using

37mm Teflon filters (Pall, Teflo 2.0 µm) and two different pump setups. During the July/August monitoring period, SKC universal pumps (SKC Inc. model 224-PCXR8) set at 4.0 liters per minute (LPM) with KTL $PM_{2.5}$ cyclones (BGI, model GK2.05) were used. During the October/November sampling period, SKC AirChek 2000 pumps set at 1.5 LPM with Triplex $PM_{2.5}$ cyclones (BGI, model SCC 1.062) were used. Previous research has shown that the KTL and Triplex cyclones collect $PM_{2.5}$ at a similar rate ([Triplex] = 1.061*[KTL] + 2.971; R^2 = 0.756) with the Triplex Cyclone producing a slightly higher value (Kim et al., 2005).

Sampled filters were frozen within two hours of the end of each 24-hr sampling period to prevent partial volatilization of the collected aerosols. Filters remained frozen during all storage and transportation periods. The filters were analyzed in the Air Quality Lab in the Department of Environmental Health Science at the University of Georgia (UGA). Filters were desiccated in climate controlled conditions (20.6 ± 1.4°C) for a 48-hr period prior to the initial weighing of the unused filters and the weighing the sampled filters. Each filter was weighed twice before and after sampling using a Cahn C-35 microbalance with a sensitivity of ±1 µg following the EPA's Quality Assurance Guidance Document (U.S.EPA, 1998). If the duplicate measurements were not within the +/- 5 µm criteria, the filters were measured a subsequent time. The PM concentrations were derived from the average mass of all filter weights. Air densities during weighing sessions, nominal densities of calibration masses, and control filters were used to adjust the balance readings for the buoyancy effect of air (Koistinen, 1999). Damaged or overloaded filters were described and recorded in the field.

Real-time $PM_{2.5}$ levels were measured using DustTrak aerosol monitors with dataloggers (TSI Inc., model 8520) and were recorded continuously throughout the entire sampling periods. The aerosol monitors were cleaned and zero-checked every 72 hours. The aerosol monitors were later run in parallel for 24 hours to establish a concentration coefficient to adjust for inter-instrumentation variation. An inherent problem with the DustTrak aerosol monitors is that they are factory calibrated using the respirable fraction of standard ISO 12103-1, A1 test dust (Arizona Test Dust; aerodynamic diameter of 4.4 μm), which may not be representative of the PM being sampled. Fine aerosols less than 1 μm scatter more light per unit mass than particles greater than 1 μm, and therefore their presence may increase the aerosol monitor's readings when it is exposed to a high percentage of fine aerosols. Fumes, haze and combustion aerosols such as cigarette smoke or diesel exhaust often scatter two to three times more light per unit mass than the ISO fine dust used during calibration but sometimes as high as a factor of five (MacIntosh, 2002; Volckens, 1999). In order to rectify this potential problem, a DustTrak aerosol monitor was collocated with a gravimetric $PM_{2.5}$ setup on the roof of CH throughout the entire sampling period. At the end of the study the gravimetric concentrations were measured at the University of Georgia and a concentration ratio between the two designs was established in order to adjust the real-time data as directed by manufacturer. The CH rooftop DustTrak measured a mean concentration 2.43 times higher than the CH DustTrak throughout the monitoring period. All real-time $PM_{2.5}$ concentrations were decreased to 41% of the original concentration ($1 \div 2.43$) so that time-integrated and real-time concentrations are comparable.

Real-time CO levels were continuously measured using Langan CO monitors (Langan Products Inc., model T15v). The Langan monitors were calibrated at the University of Georgia at the beginning and the end of the study to adjust the instruments if needed and to detect any fluctuations over time in the Langan's measurements. The Langan monitors were calibrated with a >99.999% N_2 (zero gas) and a 50 ppm CO gas. Both real-time CO and $PM_{2.5}$ monitors were time-synchronized to sample in parallel and logged their respective mean concentrations at 30-second intervals.

NO_2 was collected using passive diffusion tubes developed by Palmes et al. (1976). These passive diffusion tubes collect NO_2 at a rate of 0.92mL/min, and each tube continuously samples for a 24-hr period. NO_2 analyses were done in the Environmental Exposure Assessment Laboratory at Emory University. NO_2 concentrations were determined spectrophotometrically (Milton Roy Company, Spectronic 20D) from a ten-point, cubic-spline fit calibration curve.

VOCs were collected using passive diffusion stainless steel tubes (90mm long, 6.3mm OD and 5mm ID, Perkin-Elmer) packed with Tenax™ TA (60/80 mesh, 200 mg) as an adsorbent. Each VOC tube sampled for a 24-hr period. VOC samples were analyzed at the Georgia Tech Research Institute using an automated thermal desorption system (ATD400) coupled to a Hewlett-Packard model 5890A gas chromatograph/VG model Trio 1 mass spectrometer (GC/MS). Sample volume was calculated from the passive uptake rate of 0.54 mL/minute (Brown 1993, 1998, 2000).

Statistical Analysis

Twenty-four-hour mean concentrations of $PM_{2.5}$, CO, NO_2 and VOCs were calculated throughout each sampling period at both monitoring stations. Twenty-four-hour mean pollutant concentrations were compared between the two sites during the same monitoring period using paired, two-tailed t-tests. Twenty-four-hour mean concentrations from the same site over both monitoring periods were compared using non-paired, two-tailed t-tests. A significance level of $p < .05$ was used for all statistical tests.

Correlations between meteorological values and mean hourly $PM_{2.5}$ and CO concentrations between 6AM and 9PM were determined using a two-tailed partial correlation test. The partial correlations were controlled for in-day (using a time variable) and day-to-day (using a date variable) weather variation in order to eliminate bias.

Results

Mean Pollutant Concentrations at City Hall and Trujillo Airport Fixed Sites by Location

Table 3-1 presents the mean concentrations (± the standard error) of all the pollutants measured at both CH and TA stations within each sampling period. When means differed statistically between locations within the same monitoring season (13 of the 18 comparisons), the CH means were higher than the TA means in every comparison for every pollutant except for the October/November real-time CO, where CO levels were higher at the TA site.

Mean NO_2 concentrations at CH were 9.4 and 9.8 ppb in July/August and October/November, respectively. A short sampling time of 24-hrs for each Palmes tube and the low NO_2 concentrations present at the TA resulted in NO_2 concentrations that were not statistically different from the July/August (p-value = 0.38) and October/November (p-value = 0.96) field blanks. In-house analyses over the last 15 years using the same analytical equipment and techniques have shown that the LOD of the process is approximately 8 ppb. The NO_2 values in Table 3-1 are listed as "LOD", representing that a large percentage of the samples had concentrations that were below the limit of detection and therefore should be interpreted cautiously.

Table 3-1 illustrates the BTEX VOC concentrations at each monitoring station and during each sampling period. The highest mean toluene (34.7 $\mu g/m^3$), ethylbenzene (5.7 $\mu g/m^3$), p-xylene (11.1 $\mu g/m^3$), o-xylene (3.7 $\mu g/m^3$) and m-xylene (20.7 $\mu g/m^3$) concentrations were measured at CH in July/August. The CH's and the TA's benzene concentration in October/November means were 5.8 and 3.5 $\mu g/m^3$ respectively while 100% of the July/August VOC tubes measured benzene concentrations below the limit of detection (2.76 $\mu m/m^3$) and are labeled "LOD" in Table 3-1. For daily samples below the minimum detection limits of the GC-MS, the square root of the limit of detection of the VOC in question was used in the calculation the VOC mean throughout the sampling period. Depending on the molecular weight of the VOC and the duration of the sample, the minimum detection limit ranged between one to three $\mu g/m^3$.

Mean Pollutant Concentration at Fixed Sites by Sampling Period

Table 3-2 presents the difference between the average pollution concentrations at both monitoring stations during each monitoring period. When the mean pollutant concentrations within one study period were statistically different from the other study period (14 of the 18 comparisons), the mean concentrations were higher in July/August than in the October/November sampling period for each pollutant except for the TA CO and the benzene at both TA and CH locations.

Correlations Between Pollutant Concentrations and Weather Phenomenon

Table 3-3 presents the partial correlations between hourly meteorological values (6AM to 9PM) with real-time $PM_{2.5}$ and CO for all sample periods. Correlations were controlled for within-day and day-to-day variation of factors that could potentially bias the data using SPSS version 12.0.1. Pearson correlation coefficient values (r) illustrate the strength of the linear relationship between individual weather phenomena and pollutant concentrations. Strong correlations, when observed, were not consistent throughout the study. The strongest correlations included CO and temperature ($r = -0.874$), humidity ($r = 0.843$) and wind speed ($r = -0.523$), but these trends were only seen during July/August at CH and during October/November at TA. Correlations between pollutants and precipitation values were not analyzed due to the absence of measurable precipitation within the arid environment.

"Natural Experiment" (El Dia Sin Autos ["The Day Without Cars"]) Investigation

The real-time aerosol monitor measuring the street-level $PM_{2.5}$ concentrations outside CH from July 15 to August 4 measured a mean real-time $PM_{2.5}$ concentration of 44 $\mu g/m^3$ while the aerosol monitor atop CH measured a mean $PM_{2.5}$ concentration of 32 $\mu g/m^3$ (37% lower on the rooftop than at street-level).

On July 15, 2003 no motor vehicles were allowed within the *Avenida España* perimeter from 8AM to 6PM for the inaugural *El Dia Sin Autos* ("The Day Without Cars"). During this time period, the closest vehicular traffic to the CH air monitoring station was 430 meters south on *Avenida España* (Figure 3-2). Figure 3-4 shows the mean 30-min street-level $PM_{2.5}$ concentration (± 1 st. deviation) measured outside CH on "The Day Without Cars" compared to the corresponding mean 30-min street-level $PM_{2.5}$ for the remaining days during the sampling period where traffic flow was not impeded (n = 19 days). The mean 8AM to 6PM real-time $PM_{2.5}$ concentrations with and without cars were 44 $\mu g/m^3$ and 22 $\mu g/m^3$ respectively (100% higher with than without cars). Figure 3-5 depicts the mean hourly $PM_{2.5}$ and CO concentrations atop CH during "The Day Without Cars" compared to the mean hourly concentrations measured at the rooftop CH monitoring station during the remainder of the July/August monitoring period. The mean 8AM to 6PM real-time $PM_{2.5}$ concentrations at CH with and without cars between July 15 and August 4 were 25 $\mu g/m^3$ and 20 $\mu g/m^3$ respectively (25% higher with than without cars). The mean 8AM to 6PM CO concentrations with and without cars were 0.51 and 0.30 ppm (68% higher with than without cars).

Discussion

The mean time-integrated $PM_{2.5}$ concentrations measured during both seasons and at both monitoring stations were approximately twice the concentration of the USEPA NAAQS and the Peruvian National Ambient Air Standards annual $PM_{2.5}$ limit (Table 3-4) (Peru, 2001 and U.S. CFR). However, only nine weeks of ambient $PM_{2.5}$ measurements were collected in the current study so it is not possible to definitively determine if Trujillo is in compliance with these annual $PM_{2.5}$ standards. However, if the concentrations observed in the current study remained relatively constant throughout the year, the annual $PM_{2.5}$ standards would be exceeded.

During the nine weeks of air monitoring, there was one incident at CH (July 4-5; 67.52 $\mu g/m^3$) in which the mean 24-hr $PM_{2.5}$ concentration was above the 24-hr Peruvian standard of 65 $\mu g/m^3$. However, the standard says that the three year average of the 98^{th} percentile of 24-hr concentrations must not exceed 65 $\mu g/m^3$. Therefore, more ambient data is needed to determine whether if the daily standard is out of compliance.

The street-level aerosol monitor outside of CH continuously recorded $PM_{2.5}$ concentrations for 20 continuous days in July and August. The mean street-level $PM_{2.5}$ concentration was 44 $\mu g/m^3$ during the sampling period and the corresponding $PM_{2.5}$ concentration three stories above on the roof of CH was 32 $\mu g/m^3$. The highest average $PM_{2.5}$ concentrations throughout the twenty days of street-level sampling occurred during the morning (7:00-9:00am) with concentrations regularly over 60 $\mu m/m^3$ (Figure 3-5).

NO_2 and CO concentrations measured at both locations and during both seasons did not exceed either NAAQS or Peruvian National Standards. Most NO_2 samples resulted in concentrations below the limit of detection indicating low NO_2 concentrations.

Many of the daily VOC samples contained BTEX concentrations below the minimum limit of detection (ranging from one to three $\mu g/m^3$ depending on sampling time and molecular weight of the VOC).

Mean pollutant concentrations were higher at CH than TA in 70% of the pollutant comparisons (Table 3-1). The higher pollution concentrations at the CH monitoring station were expected due to the closer proximity to a larger vehicular fleet and more commercial, industrial and residential establishments opposed to the area surrounding TA.

The mean pollutant concentrations were statistically higher during the July/August period than during the October/November monitoring period in 77% of the comparisons (Table 3-2). These trends indicate that seasons and/or seasonal fossil fuel combustion use may play a role in pollution concentrations within Trujillo. However, due to a lack of seasonal information on roadway density, agricultural field burning and commercial/industrial/residential pollution emission in the current study, we can not definitely say whether the changing pollution concentrations are primarily due to a seasonal climate change, a change in ambient pollution input, or a combination of both.

Meteorological data, although only available for only 16 hours a day, produced several significant correlations with real-time $PM_{2.5}$ and CO. However, the partial correlations were often weak ($r < 0.4$) indicating that most of the weather factors had little to no association with the pollutant concentrations. A few weather factors were moderately to strongly associated with CO including temperature, humidity and wind speed but these associations were inconsistent throughout the study period. Normally there is an inverse correlation between CO and temperature due to less efficient

combustion at lower temperatures. However, the temperature difference seen (15ºF difference between night and day) is small enough that the correlation may be artifactual.

Conclusions

The data suggest that ambient $PM_{2.5}$ levels in urban and rural Trujillo likely exceed annual and potentially exceed daily Peruvian and US EPA ambient air quality standards, and as such warrant public health concern. Further, the data suggest that downtown Trujillo street-level $PM_{2.5}$ is reduced 50% when automobile traffic is removed from the historic downtown area. Continuous ambient monitoring is needed throughout the year to adequately determine compliance of ambient pollution concentrations and seasonal variation of pollutants.

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Table 3-1. Mean pollutant concentration comparisons by location within the same monitoring period

Season	Pollutant	Sample Size (n)	Unit	City Hall Mean ± st. error	Airport Mean ± st. error	p-value (α = 0.05)
July/Aug	$PM_{2.5}$ (time-integrated)	26	$\mu g/m^3$	36.1 ± 1.8	30.4 ± 1.5	**0.019**
	NO_2	34	ppb	9.4 ± 0.9 (LOD)	-1.0 ± 0.8 (LOD)	**<0.001**
	CO	33	ppm	0.76 ± 0.05	0.04 ± 0.01	**<0.001**
	benzene	28	$\mu g/m^3$	LOD	LOD	1.000
	toluene	24	$\mu g/m^3$	34.7 ± 12.0	18.8 ± 4.1	0.331
	ethylbenzene	24	$\mu g/m^3$	5.6 ± 0.4	2.4 ± 0.2	**<0.001**
	p-xylene	24	$\mu g/m^3$	11.0 ± 0.7	6.9 ± 0.1	**<0.001**
	o-xylene	24	$\mu g/m^3$	3.6 ± .6	LOD	**0.005**
	m-xylene	24	$\mu g/m^3$	20.7 ± 1.0	12.3 ± 0.4	**<0.001**
Oct/Nov	$PM_{2.5}$ (time-integrated)	24	$\mu g/m^3$	26.2 ± 1.1	26.0 ± 2.0	0.801
	NO_2	28	ppb	9.8 ± 0.5 (LOD)	1.2 ± 1.1 (LOD)	**<0.001**
	CO	28	ppm	0.52 ± 0.10	0.65 ± 0.05	**<0.001**
	benzene	21	$\mu g/m^3$	5.8 ± 0.4	3.5 ± 0.5	**0.003**
	toluene	21	$\mu g/m^3$	23.0 ± 7.9	7.0 ± 2.9	**0.007**
	ethylbenzene	21	$\mu g/m^3$	1.4 ± 0.2	1.2 ± 0.1	0.538
	p-xylene	21	$\mu g/m^3$	2.5 ± 0.2	1.9 ± 0.2	**0.003**
	o-xylene	21	$\mu g/m^3$	1.6 ± 0.2	1.4 ± 0.2	0.436
	m-xylene	21	$\mu g/m^3$	3.3 ± 0.5	2.0 ± 0.4	**0.006**

p-value refers to the statistical difference between the mean pollution concentration at both locations

LOD = >95% of samples below the limit of detection and/or had concentrations similar to blanks

LOD of NO_2 were approximately 24 ppb for a 24-hour sample

LOD of VOCs ranged between 1 and 3 $\mu g/m^3$ depending on molecular weight and sample duration

Table 3-2. Mean pollution concentration comparisons between July-Aug. and Oct.-Nov., 2003.

Location	Pollutant	Unit	July/Aug Sample Size (n)	July/Aug Mean ± st. error	Oct/Nov Sample Size (n)	Oct/Nov Mean ± st. error	p-value (α = 0.05)
City Hall	$PM_{2.5}$ (time-integrated)	$\mu g/m^3$	26	36.1 ± 1.8	28	26.2 ± 1.1	**<0.001**
	NO_2	ppb	34	9.4 ± 0.9 (LOD)	28	9.8 ± 0.5 (LOD)	0.746
	CO	ppm	36	0.76 ± 0.05	26	0.52 ± 0.10	**<0.001**
	benzene	$\mu g/m^3$	28	LOD	29	5.8 ± 0.4	**0.020**
	toluene	$\mu g/m^3$	28	34.7 ± 12.0	29	23.0 ± 7.9	0.466
	ethylbenzene	$\mu g/m^3$	28	5.6 ± 0.4	29	1.4 ± 0.2	**<0.001**
	p-xylene	$\mu g/m^3$	28	11.0 ± 0.7	29	2.5 ± 0.2	**<0.001**
	o-xylene	$\mu g/m^3$	28	3.6 ± .6	29	1.6 ± 0.2	**0.016**
	m-xylene	$\mu g/m^3$	28	20.7 ± 1.0	29	3.3 ± 0.5	**<0.001**
Airport	$PM_{2.5}$ (time-integrated)	$\mu g/m^3$	33	30.4 ± 1.5	23	26.0 ± 2.0	0.225
	NO_2	ppb	34	-1.0 ± 0.8 (LOD)	27	1.2 ± 1.1 (LOD)	0.115
	CO	ppm	35	0.04 ± 0.01	28	0.65 ± 0.05	**<0.001**
	benzene	$\mu g/m^3$	28	LOD	23	3.5 ± 0.5	**<0.001**
	toluene	$\mu g/m^3$	28	18.8 ± 4.1	23	7.0 ± 2.9	**0.025**
	ethylbenzene	$\mu g/m^3$	28	2.4 ± 0.2	23	1.2 ± 0.1	**<0.001**
	p-xylene	$\mu g/m^3$	28	6.9 ± 0.1	23	1.9 ± 0.2	**<0.001**
	o-xylene	$\mu g/m^3$	28	LOD	23	1.4 ± 0.2	0.274
	m-xylene	$\mu g/m^3$	28	12.3 ± 0.4	23	2.0 ± 0.4	**<0.001**

p-value refers to the statistical difference between the mean pollution concentration at both locations

LOD = >95% of samples below the limit of detection and/or had concentrations similar to blanks

LOD of NO_2 were approximately 24 ppb for a 24-hour sample

LOD of VOCs ranged between 1 and 3 $\mu g/m^3$ depending on molecular weight and sample duration

Table 3-3. Correlations between meteorological values and real-time $PM_{2.5}$ and CO concentrations controlled for within-day and day-to-day weather variations.

Pollutant	Location	Season	Statistic	Temp	Dew Point	Humidity	Pressure	Visibility	Wind Speed
$PM_{2.5}$	City Hall	July-Aug	Pearson (r)	-0.389	-0.252	0.307	0.177	-0.263	-0.255
			p-value	**<0.001**	**<0.001**	**<0.001**	**0.002**	**<0.001**	**<0.001**
		Oct-Nov	Pearson (r)	-0.222	-0.119	0.214	0.308	-0.257	-0.252
			p-value	**0.001**	0.078	**0.001**	**<0.001**	**<0.001**	**<0.001**
	Airport	July-Aug	Pearson (r)	-0.323	-0.143	0.289	0.089	-0.311	-0.151
			p-value	**<0.001**	**0.013**	**<0.001**	0.120	**<0.001**	**0.008**
		Oct-Nov	Pearson (r)	-0.152	-0.161	0.120	0.193	-0.209	-0.203
			p-value	**0.024**	**0.017**	0.074	**0.004**	**0.002**	**0.002**
CO	City Hall	July-Aug	Pearson (r)	-0.644	-0.283	0.569	0.132	-0.233	-0.530
			p-value	**<0.001**	**<0.001**	**<0.001**	**0.022**	**<0.001**	**<0.001**
		Oct-Nov	Pearson (r)	0.446	0.219	-0.426	-0.127	0.204	0.265
			p-value	**<0.001**	**0.001**	**<0.001**	0.060	**0.002**	**<0.001**
	Airport	July-Aug	Pearson (r)	0.052	0.045	-0.038	-0.096	-0.233	-0.019
			p-value	0.369	0.434	0.512	0.096	<0.001	0.743
		Oct-Nov	Pearson (r)	-0.874	-0.412	0.843	0.072	-0.243	-0.523
			p-value	**<0.001**	**<0.001**	**<0.001**	0.289	**<0.001**	**<0.001**

Table 3-4. Measured Concentrations vs. Peruvian and USEPA ambient air quality standards

Pollutant	Averaging Times	Peruvian National Standards*	1997 USEPA NAAQS+	Avg. City Hall	Avg Airport
$PM_{2.5}$	365 days 24-hour	15.0 µg/m^3 (1) 65 µg/m^3 (2)	15.0 µg/m^3 (1) 65 µg/m^3 (2)	31 µg/m^3	28.6 µg/m^3
NO_2	365 days 1-hour	100 µg/m^3 (53 ppb) 200 µg/m^3 (106 ppb) (4)	100 µg/m^3 (53 ppb) N/A	9.6 ppb (LOD)	1.2 ppb (LOD)
CO	8-hour 1-hour	10 mg/m^3 (8.7 ppm) 30 mg/m^3 (26.1 ppm)	10 mg/m^3 (9 ppm) (3) 40 mg/m^3 (35 ppm) (3)	0.79 ppm	0.31 ppm

LOD represents samples below the limit of detection and/or concentrations similar to blanks

[1] The 3-year average of the annual arithmetic mean $PM_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 µg/m^3.

[2] The 3-year average of the 98th percentile of 24-hour concentrations at each population--oriented monitor within an area

must not exceed 65 µg/m^3.

[3] Not to be exceeded more than once per year.

[4] Not to be exceeded more than 24 times per year.

[5] The expected annual arithmetic mean PM_{10} concentration at each monitor within an area must not exceed 50.0 µg/m^3.

[6] Not to be exceeded more than 3 times per year.

* - Peru National Counsel of the Environment, 2001.

+ - United States CFR Title 40; Part 50

Figure 3-1. Location of Trujillo, Peru within South America

Figure 3-2. Downtown Trujillo, Peru

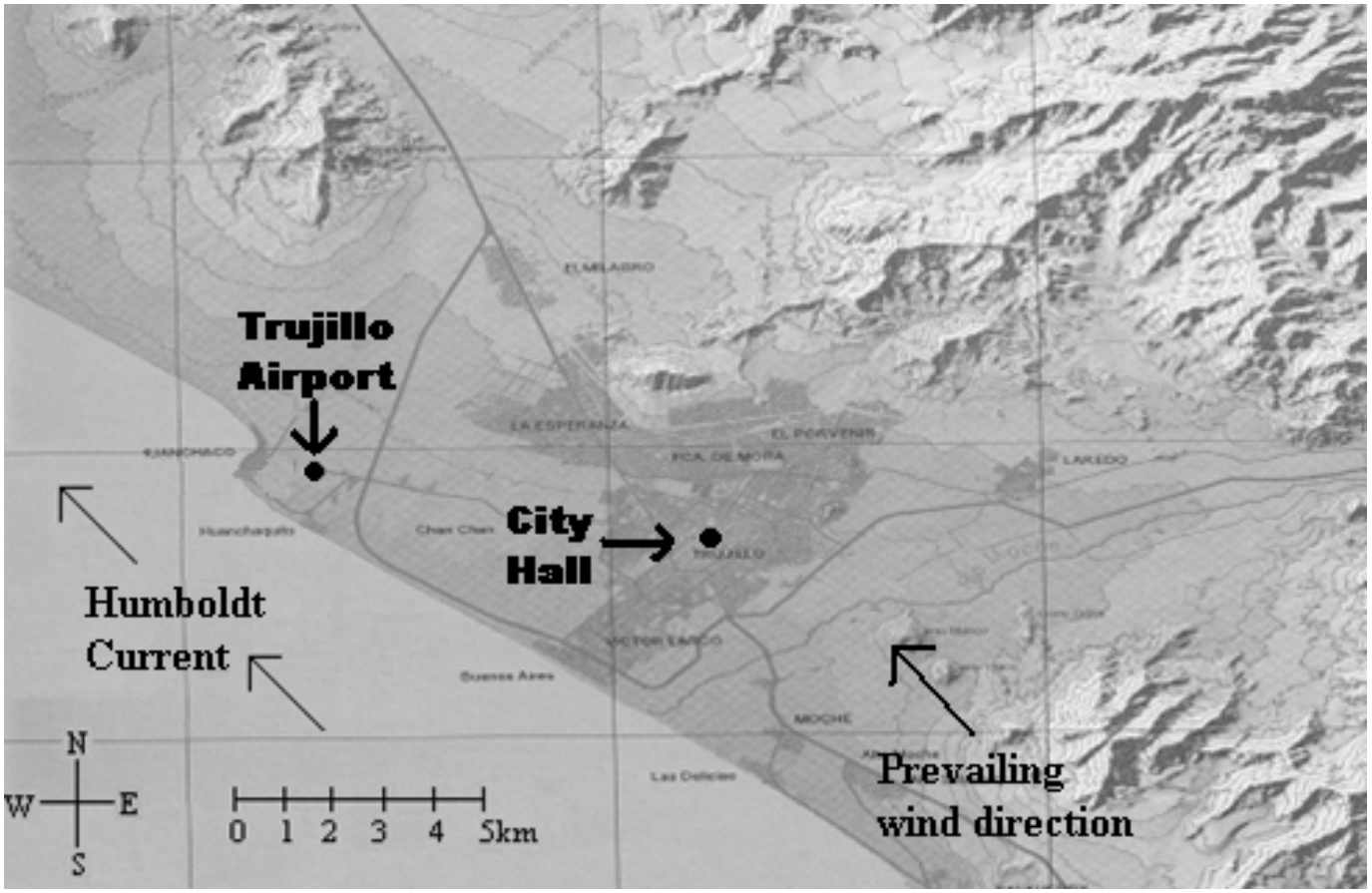

Figure 3-3. Trujillo, Peru terrain and location of monitoring sites

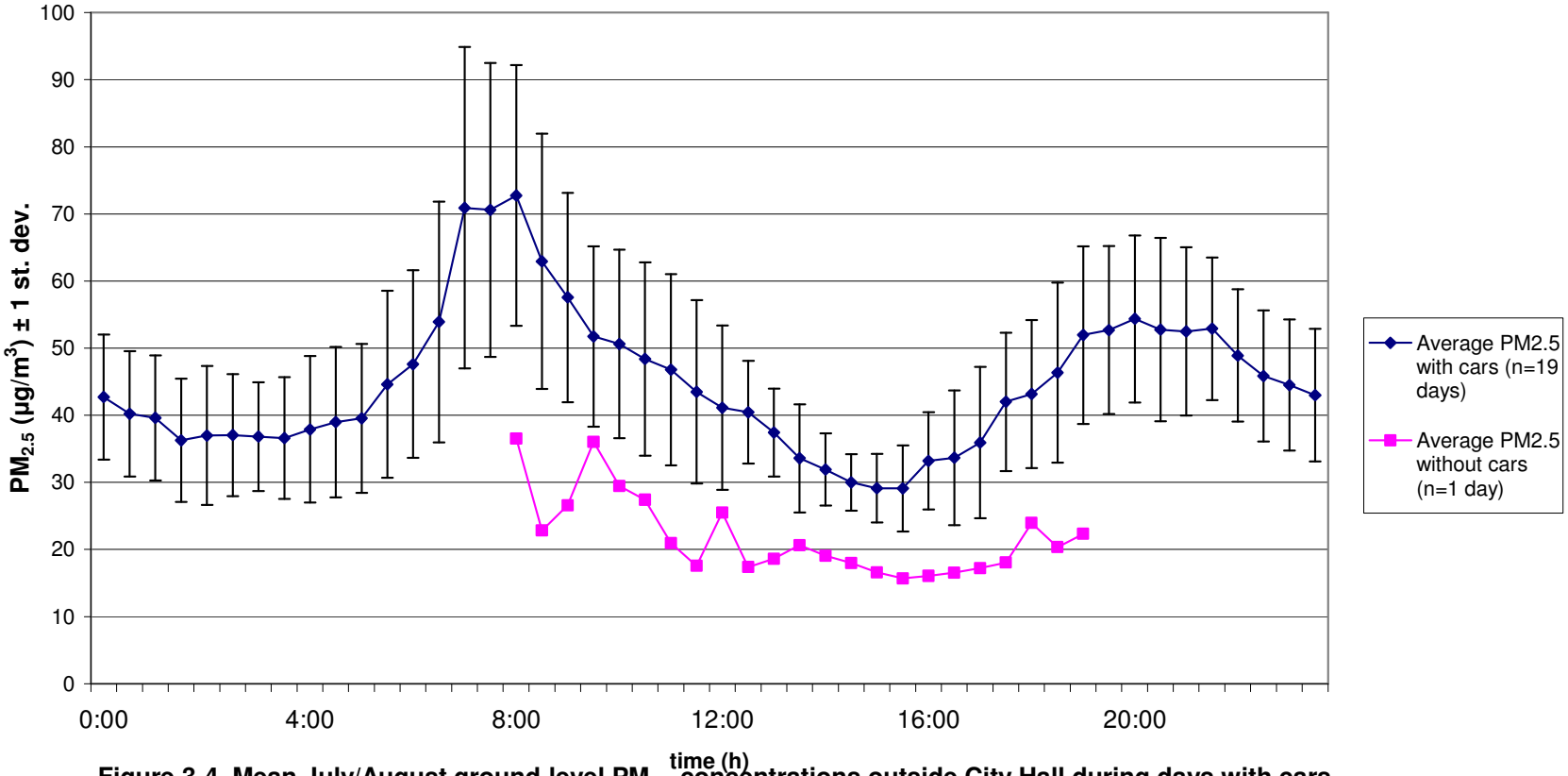

Figure 3-4. Mean July/August ground-level $PM_{2.5}$ concentrations outside City Hall during days with cars vs. days without cars within *Avenida España*.

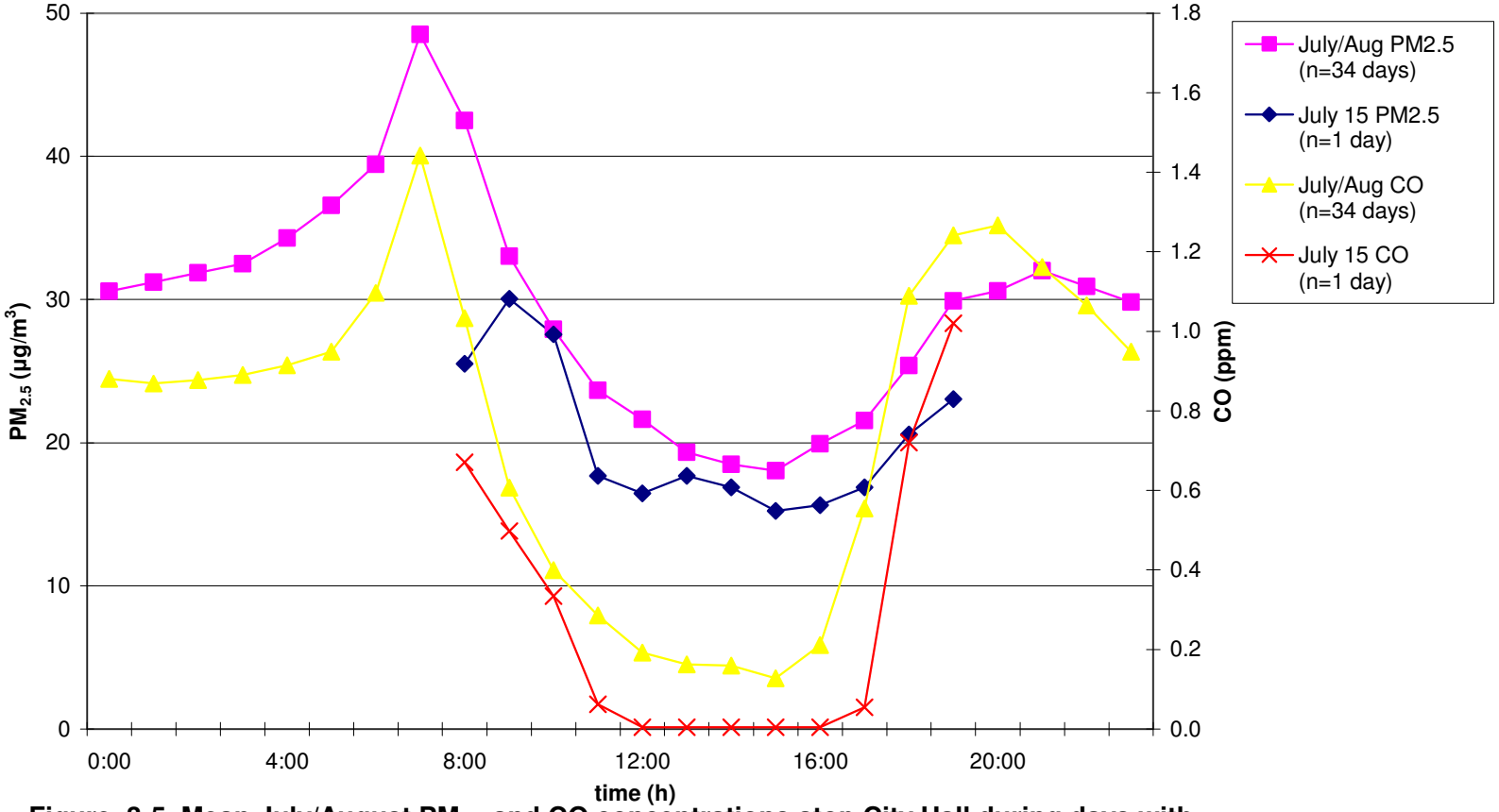

Figure. 3-5 Mean July/August $PM_{2.5}$ and CO concentrations atop City Hall during days with cars present vs. no cars present within *Avenida España*.

CHAPTER 4

AMBIENT AND STREET-LEVEL POLLUTION LEVELS DURING DIFFERENT PERIODS OF DAY IN BAGUIO CITY, PHILIPPINES[1]

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[1]Cassidy, B.E.; Alabanza-Akers, M.A.; Akers, T; Hall, D.; Ryan, P.B.; Bayer, C.W.; Naeher, L.P. 2005. To be submitted to Environmental Health Perspectives.

ABSTRACT

Ambient particulate matter $\leq$ 2.5µm ($PM_{2.5}$) and $\leq$ 10µm (PM_{10}) in aerodynamic diameter, carbon monoxide (CO), nitrogen dioxide (NO_2) and select volatile organic compounds (VOCs) were measured at a downtown, fixed monitoring station from December 14-25, 2004 within Baguio City, Philippines, a city of 252,386. Also, real-time $PM_{2.5}$, PM_{10}, and CO was measured at 30 locations within downtown Baguio for 15-minutes during the early morning (4:50-6:30am), morning rush hour (6:30-9:10am) and afternoon rush hour (3:40-5:40pm). Site-specific environmental characteristics were used in multiple regression models for real-time, street-level $PM_{2.5}$, PM_{10} and CO among the three sampling periods. Early morning street-level $PM_{2.5}$ was not significantly different from the rush hours $PM_{2.5}$ concentrations in spite of a two-fold difference in automotive density (p-values > 0.450) because of nocturan inversions and the resulting limited mixing of the atmosphere. The average street-level $PM_{2.5}$ and PM_{10} was highest before morning rush hour (110±8 µg/m^3) and the highest average PM_{10} was during the morning rush hour (124±11 µg/m^3). CO concentrations statistically differed at street-level sites between early morning (3.0±1.7 ppm) and morning rush hour (4.1±2.3 ppm) (p = 0.039) and early morning and afternoon rush hour (4.5±2.2 ppm) (p = 0.007). Multiple regression modeling showed traffic intensity was significant with pollution levels early in the morning ($PM_{2.5}$ p = 0.021; PM_{10} p = 0.048) and in both rush hours (CO morning rush p = 0.048; CO afternoon rush p = 0.034). Twenty-four hour average ambient concentrations were: $PM_{2.5}$ = 72.9 ± 21 µg/m^3; CO = 2.61 ± 0.6 ppm; NO_2 = 27.7 ± 1.6 ppb; benzene = 8.4 ± 1.4 µg/m^3; toluene = 173.7 ± 100.9 µg/m^3; ethylbenzene = 4.6 ± 2.0 µg/m3; P-xylene = 4.4 ± 1.9 µg/m^3; M-xylene = 10.2 ± 4.4 µg/m^3; O-xylene = 7.5 ± 3.2 µg/m^3. Street-level and ambient PM concentrations are consistently

above 1997 Philippine Clean Air Act and the US National Ambient Air Quality Standards and therefore pose a public health concern.

Introduction

Ambient air pollution is a major environmental health problem that affects both developed and developing nations, particularly within urban areas. Air pollution includes a mixture of pollutants at various concentrations including but not limited to particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOCs) and nitrogen oxides (NOx). 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). It is estimated that over 500,000 people in Asia die each year from diseases related to air pollution (WHO, 2005).

Epidemiological studies have shown a correlation between increases in exposure to air pollutants and increases in morbidity and mortality, particularly among those with respiratory or cardiovascular disease. Examples of associated morbidity include asthma, chronic obstructive pulmonary disease, cardiovascular disease, lower birth weights, cancer, and premature births (ATSDR, 1997; ATSDR, 2000; Dockery, 1993; HEI, 2001; WHO, 2000). Furthermore, there is a growing database of studies showing a strong correlation between exposure to ambient air pollution and negative health effects in the developing world (Cohen et. al, 2005; HEI, 2004; Romieu et. al, 2002; WHO, 2002; WHO, 2004).

A large percentage of urban areas within the Philippines exceed the 1997 Philippine Clean Air Act (CAA) standards primarily due to the growing vehicular populations and industrial

activities within cities (Republic of the Philippines, 2003). The 2001 Philippine Emission Inventory stated that mobile sources contribute 62% of the total CO, 20% of the total suspended particulates (TSP) and 9% of the total NOx within the Philippines (Republic of the Philippines, 2003). Although continuous air pollution monitoring throughout the country is limited, current statistics show that the annual standard for TSP (90 $\mu m/m^3$) is being exceeded at 70% (22 out of 32) of the nationwide monitoring sites with Manila having the highest concentrations (World Bank, 2002). The only air pollutant that has been consistently monitored throughout the country over the past several decades is TSP while PM_{10}, $PM_{2.5}$, NOx, CO and VOC monitoring have either been recently established or are not regularly monitored at all (Republic, 2003; World Bank, 2002)

In 2000 and 2001 Baguio City was noted as one of the most polluted cities within the Philippines in relation to PM (World Bank, 2002). Data on Baguio's ambient air quality outside of TSP is currently lacking. Baguio City is designated as "The Summer Capital of the Philippines" because of its temperate climate at an elevation of 5,000 feet. Due to the importance of Baguio as a tourist destination, it is important to adequately characterize the air quality of the city and to identify potential air pollution sources.

The objectives of this study were: 1) to determine the ambient pollution concentrations of $PM_{2.5}$, PM_{10}, CO, NO_2 and select VOCs (including BTEX [benzene, toluene, ethylbenzene and xylenes] and; 2) to determine street-level air pollution concentrations of $PM_{2.5}$, PM_{10} and CO at select locations within the Central Business District (CBD) of Baguio City during three time periods associated with varying automotive densities and commercial activities. The street-level data taken throughout the CBD were used to determine the associations between pollution

concentrations, potential sources and physical entities in the environment that would either help facilitate or impede the diffusion of these pollutants within the atmosphere.

Methods

Study Location

This study took place in Baguio City, Philippines December 13-22, 2004. Baguio City is a city of approximately 250,000 located at 16°N and 120°E on the island of Luzon in the Pacific Ocean (Figure 4-1). The city is located approximately 5,000 feet above sea level within the Cordillera Mountains and has a temperate climate with an average temperature of 68°F (20°C) throughout the year. During the warmer months thousands of visitors from the lowlands and Manila take their annual exodus to Baguio City to seek temporary relief from the higher temperatures at lower elevations. During the peak of the annual tourist influx, particularly during the Lent period, transients triple the city's population (WOWPhilippines, 2005)

The CBD of Baguio City is located at the bottom of a mountain basin where the natural airflow through the city is impeded by the surrounding mountains, resulting in an increase in frequency and intensity of nocturnal inversions in Baguio City. The asphalt-paved streets within the CBD are generally lined with buildings of two or three stories high with some as high as six stories. About half the area of the city has a slope of 25% or more. Outside of the CBD the land changes from dense commercial zones to less dense areas that are often wooded. Five kilometers outside of the CBD is Camp John Hay (CJH), a former recreation base for American soldiers now used as a public resort covering approximately 1700 acres.

Monitoring Sites

Street-level air pollution monitoring was conducted at 30 sites within the CBD including sites with varying levels of pedestrian, automotive and commercial activity. These locations were similar to those 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, 2004).

Street-level, real-time $PM_{2.5}$, PM_{10} and CO were measured at each site during three distinct monitoring periods each weekday between December 13-22, 2004. Fifteen minutes of continuous, real-time data were collected once at each site between 4:50-6:30AM (low automotive density), 6:30-9:10AM (morning rush hour) and 3:40-5:40PM (afternoon rush hour). Although the afternoon rush hour peaked at approximately 6PM, sampling ended by 5:40PM due to safety issues. All sampling took place on weekdays to increase comparability among the sites.

In addition to the 30 sites located within the CBD, a fixed monitoring station (Session Road monitoring station) was established to collect 24-hr ambient $PM_{2.5}$, PM_{10}, CO, NO_2 and BTEX VOCs concentrations throughout the entire sampling period (December 14-25, 2003). The station was located on the third floor balcony underneath a building overhang facing Session Road, a major six-lane road that acts as the commercial artery of Baguio (Figure 4-2). Due to Session Road's commercial density and the continuous presence of through traffic, there is normally a large automotive and pedestrian presence on Session Road throughout the majority of the day.

For 32 hours on December 18-19 (Saturday-Sunday), real-time $PM_{2.5}$, PM_{10} and CO were measured at ground level in CJH. The monitoring site was located within a predominantly

wooded area away from air pollution point sources, therefore containing a low air pollution concentration. This location was chosen in order to produce a baseline pollution concentration for comparison to the ambient levels measured at the Session Road monitoring station in Baguio City's CBD. Only 32 hours of sampling was taken because the monitoring equipment was used in the street-level study Monday through Friday.

Session Road Monitoring Station Equipment Description

The following pollutants were continuously measured at the Session Road fixed monitoring station: $PM_{2.5}$ (real-time and time-integrated), PM_{10} (real-time), CO (real time), NO_2 and VOC (both passive diffusion time-integrated).

Twenty-four-hour time-integrated $PM_{2.5}$ samples were collected in duplicate using 37mm Teflon filters (Pall, Teflo 2.0µm), Harvard Impactor plates and SKC universal pumps (SKC Inc. model 224-PCXR8) set at 4.0 liters per minute. Sampled filters were frozen within one hour of the end of each 24-hr sampling period to prevent volatilization. Filters remained frozen during all storage and transportation periods. The filters were analyzed in the Air Quality Lab in the Department of Environmental Health Science at the University of Georgia (UGA). Filters were desiccated in climate controlled conditions (20.6 ± 1.4°C) for a 48-hr period prior to the initial weighing of the unused filters and the weighing of the sampled filters. Each filter was weighed twice before and after sampling using a Cahn C-35 microbalance with a sensitivity of ±1 µg following the EPA's Quality Assurance Guidance Document (U.S.EPA, 1998). If the duplicate measurements were not within the +/- 5 µm criteria, the filters were measured a subsequent time. The PM concentration derived from the average mass of all filter weights. Air densities during

weighing sessions, nominal densities of calibration masses, and control filters were used to adjust the balance readings for the buoyancy effect of air (Koistinen, 1999).

Real-time $PM_{2.5}$ and PM_{10} levels were measured using laser photometer aerosol monitors with dataloggers (DustTrak—TSI Inc., model 8520). All DustTraks were run in parallel for 20-hours (eight hours at $PM_{2.5}$ and twelve at PM_{10}) at the beginning of the study to establish concentration coefficients among the DustTraks to adjust for inter-instrumentation variation. During the two weeks of sampling the DustTraks were cleaned and zero-checked every 72-hrs.

One difficulty with the DustTrak aerosol monitor is that they are factory calibrated using the respirable fraction of standard ISO 12103-1, A1 test dust (Arizona Test Dust; aerodynamic diameter of 4.4μm), which may not be representative of the PM being sampled. Fine aerosols less than 1 μm scatter more light per unit mass than particles greater than 1 μm, and their presence may increase the laser photometer's readings when exposed to a high percentage of fine aerosols. Fumes, haze and combustion aerosols such as cigarette smoke or diesel exhaust often scatter two to three times more light per unit mass than the ISO fine dust used during calibration but sometimes as high as a factor of five (MacIntosh, 2002; Volckens, 1999). In an attempt to control for this limitation of the DustTrak aerosol monitor instrument, a DustTrak was collocated with two gravimetric $PM_{2.5}$ setups at the Session Road station throughout the entire sampling period. At the end of the study, the gravimetric concentrations were measured at UGA and a concentration ratio between the real-time and gravimetric PM designs was established in order to adjust the real-time data. The DustTrak aerosol monitor only successfully captured 24-hrs of continuous data on eight of the eleven days of ambient air pollution sampling due to equipment problems. During those eight days the DustTrak measured a mean $PM_{2.5}$ concentration 1.82

(±0.16) times higher than the pump and filter gravimetric $PM_{2.5}$. All real-time $PM_{2.5}$ concentrations were decreased to 55% of the original concentration (1 ÷ 1.82) so that time-integrated and real-time concentrations are comparable.

Real-time CO levels were continuously measured using a Langan CO monitor (Langan Products Inc., model T15v). The Langan monitor was calibrated at UGA at the beginning and the end of the study with a >99.999% N_2 (zero gas) and a 100 ppm CO gas. Both real-time CO and PM monitors were time-synchronized to sample in parallel and logged their respective mean concentrations at 30-second intervals.

Nitrogen dioxide was measured using Palmes Tubes (Palmes, 1976). These passive diffusion tubes collect NO_2 at a rate of 0.92mL/min, and each tube continuously sampled for a 72-hr period. NO_2 analyses were done in the Environmental Exposure Assessment Laboratory at Emory University. NO_2 concentrations were determined spectrophotometrically (Milton Roy Company, Spectronic 20D) using a ten-point, cubic-spline fit calibration curve. In-house research using the same spectrophotometer over multiple studies has shown that the LOD for a 72-hr sample period is approximately 3 ppb.

Select volatile organic compounds were collected using passive diffusion stainless steel tubes (90mm long, 6.3mm OD and 5mm ID, Perkin-Elmer) packed with Tenax™ TA (60/80 mesh, 200 mg). Each VOC tube had a 72-hr sampling period that corresponded to the same sampling period of each Palmes Tube. VOC samples were analyzed at the Georgia Tech Research Institute using an automated thermal desorption system (ATD400) coupled to a Hewlett-Packard model 5890A gas chromatograph/ VG model Trio 1 mass spectrometer

(GC/MS). Sample volume was calculated from the passive uptake rate of 0.54 mL/minute (Brown 1993, 1998, 2000).

Street-level Air Sampling Equipment and Methods

One DustTrak monitoring $PM_{2.5}$, one DustTrak monitoring PM_{10} and two Langans monitoring CO in duplicate were used to characterize the street-level ambient PM and CO pollution levels. At the 30 locations within the CBD The DustTraks and Langans were located in or attached to a backpack with the sensor/air intake located at the chest of the investigator carrying the equipment (approximately 4.5 feet from the ground). During each 15-minute monitoring period the investigator carrying the equipment stood within five feet of the closest road lane. In addition to the pollutant measures, several environmental characteristics were quantified for use as explanatory variables (Table 4-1). Variables that include counts (automobiles and people) were measured by drawing an imaginary, perpendicular line across the road/sidewalk, and the count included only those who crossed the predetermined line. If the site was located at the corner of an intersection of two roads, counts included the count for each respective road. Automobiles were determined to be gasoline or diesel-fueled based upon their make/model and information from the 2002-2003 registered automobile data collected by the local government of Baguio City (Philippine DOTC, 2003).

Statistics

Complete data sets were collected on all response variables (street-level pollutant concentrations) in the study and most of the explanatory variables in Table 4-1. However, the

four variables UPWIND_SOURCE, ANY_WIND, ROAD_WIDTH and PEOPLE_MIN all contained some missing values. Twenty-six of the 90 total observations contained missing values on one of these four variables. No observations contained missing values on more than one variable, and the majority of the incomplete cases, 16 of 25, were due to missing PEOPLE_MIN measurements. The remaining 9 incomplete cases were either missing values from UPWIND_SOURCE, ANY_WIND or ROAD_WIDTH.

Although the total amount of missing data here is relatively small compared to the total dimension of the data set, there are a fairly high proportion of incomplete cases (26/90 or 28.9%). Therefore, to avoid the potential bias and inefficiency of a complete case analysis, multiple imputation was used (Schafer, 1997). Multiple imputation works by imputing, or filling in, missing values to create a complete data set. This is done several times – in our case 5 imputed data sets were created in this way. Then each imputed data set is analyzed and the results of the 5 analyses are pooled in such a way as to account for the additional error introduced by estimating the missing data and to reduce the effect of any particular imputation. Multiple imputation was accomplished with PROCs MI and MIANALYZE in SAS version 9.1. For the continuous variables ROAD_WIDTH and PEOPLE_MIN, data imputation was done using the predictive mean matching method (Schenker and Taylor, 1996) and for the dichotomous variables ANY_WIND and UPWIND_SOURCE, the logistic regression method (Rubin, 1987) of imputation was used.

The scientific interest in this analysis is in the nature of the association between the physical characteristics of the sites and the pollutant concentrations. It is of interest here to

examine these relationships for each measurement period (time of day) as well as to determine which associations differ across periods.

The primary statistical tool used to address these goals was multiple regression analysis. Regression models were developed for each pollutant (CO_AVG=average CO concentration during measurement period, PM2.5_AVG=average $PM_{2.5}$ concentration, PM10_AVG=average PM_{10} concentration) separately. In each case, data from all three daily measurement periods were included in a single model in which PERIOD main effects and interactions between PERIOD and each other explanatory variable were included to account for differences across the times of day at which data were collected. In order to account for possible within-site correlation and between site heterogeneity, these models also included random site effects. This was necessary because the models were fit to data that included multiple (non-independent) measurements from the same site. Because all three pollutant concentration variables exhibited strong heteroscedasticity (increasing variance with the mean), each response variable was modeled on the log scale to correct this problem.

A major complication in developing these regression models is the presence of multicollinearity among the explanatory variables in Table 4-1. Part of the cause of this multicollinearity is easily identified and eliminated. For example, AUTOS_MIN is the sum of GAS_MIN and DIESEL_MIN and is therefore collinear with these variables. This problem is easily solved by omitting the redundant variable AUTOS_MIN from the model-building process. However, even after taking this and other steps to rectify obvious problems, substantial multicollinearity remains among the explanatory variables initially identified for examination in

this study. For this reason, it was necessary to reduce the dimension of the predictor set as part of the modeling process.

Although variable selection procedures such as backward, forward and step-wise selection are still commonly used in applications of multiple regression, it is well known that these procedures lead to biased parameter estimators and standard errors, and invalid statistical inferences (confidence intervals that tend to be too wide, p-values that tend to be too small, detection of spurious relationships, etc.) (Harrell, 2001). To avoid these issues, the number of predictor variables in our models was reduced by using variable clustering techniques (Harrell, 2001). This approach is particularly appealing in the current investigation because several of the candidate explanatory variables in Table 4-1 clearly cluster together as measures of common underlying constructs such as "traffic intensity" and "road size".

After variable clustering, each of the main clusters identified was represented in the analyses by the first principal component of the variables belonging to that cluster (Table 4-2). Several variables were found not to cluster strongly with multiple other variables and were therefore analyzed individually. These variable clusters are intuitively reasonable. In particular, cluster 1 seems to represent traffic intensity and cluster 2 represents road size. The variables belonging to each of these first two clusters were replaced in subsequent analyses by the first principal component of the variables in that cluster. The remaining 4 variables, AVG_STORY, HILL, ANY_WIND, and UPWIND_SOURCE were retained in the analyses on their own.

After dimension reduction via variable clustering, a multiple regression model was fitted of the form:

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

where y_{ij} is the response (either ln(CO_AVG), ln(PM10_AVG), or ln(PM25_AVG)) for the *i*th site during the *j*th measurement period, $X_{1ij},\ldots,X_{6ij}$ are the explanatory variables, and $\beta_{0j},\beta_{1j},\ldots,\beta_{6j}$ are intercept and slope parameters specific to the *j*th period. In addition, b_i is a normally distributed, site-specific random effect to account for correlation 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 of this form were fit to each imputed data set using SAS PROC MIXED and these results combined with PROC MIANALYZE.

Point estimates and 95% confidence intervals for the Pearson correlation between each response variable and continuously scaled explanatory variable were computed using the Fisher Z transformation method (Fisher and van Belle, 1993).

Results

Average Ambient Concentrations at Session Road Station

Table4- 3 shows the mean (± 1 standard deviation), maximum and minimum 24-hour average of each pollutant measured at the Session Road station over the 11 days of sampling. The average gravimetric $PM_{2.5}$ was 72.9±21.2 μm/m^3 with the highest and lowest 24-hour average being 124.4 μm/m^3 and 46.7 μm/m^3, respectively. CO and NO_2 concentrations were 2.64 ± 0.6 ppm and 27.7 ± 1.6 ppb, respectively. The highest 24-hr average BTEX VOC was toluene with a concentration of 277.6 μm/m^3 and an average concentration of 173.7 μm/m^3 throughout the entire sampling period. Complete 24-hr 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 were 67.0 ± 28.2 and 81.0 ± 28.0, respectively. The twenty-four-hour mean concentrations of each pollutant except BTEX VOCs decreased as Christmas approached (last day of sampling) with the highest 24-hr average of each pollutant occurring within the first half of the monitoring period.

Volatile organic compounds and NO_2 samples ran for 72-hr periods making it harder to differentiate true 24-hr maximum and minimum concentrations. Two of the four VOC field blanks contained toluene concentrations of 288.4ug/m^3 and 14.4ug/m^3, therefore decreasing the confidence of the ambient toluene concentrations. Other than toluene, all field blanks contained VOC concentrations below the minimum detect limit.

Ambient Concentrations at CJH vs. Session Road Station

$PM_{2.5}$, PM_{10} and CO concentrations at CJH, the low pollution source background site, were measured over a 36-hour period in order to generate a comparatively lower air pollution concentration. The mean $PM_{2.5}$, PM_{10} and CO concentrations at CJH were respectively 25 ± 19 µm/m^3, 30 ± 17 µm/m^3 and 0.59 ± 0.24 ppm while the $PM_{2.5}$, PM_{10} and CO means at the Session Road station were respectively 56 ± 22 µm/m^3, 59 ± 23 µm/m^3 and 2.6 ± 0.6 ppm during the 36-hr period. The concentrations at Session Road were higher than that seen at CJH by: 224% ($PM_{2.5}$), 197% (PM_{10}) and 441% (CO). Average $PM_{2.5}$, PM_{10} and CO concentrations were compared for mean differences between the two sites using non-paired t-tests. All pollutant means were significantly different between the two locations (p-value < 0.001). However, the air pollution concentrations measured in this comparison came from only 36-hrs of air

monitoring—four of which contained rain at both locations but more intense rainfall at CJH. The short sampling time and the presence of rain (the only rain during the entire sampling period known to the researchers) potentially decrease the representability of the sample, and therefore the CJH concentrations should not be considered a strong data set for comparison.

Mean Hourly $PM_{2.5}$, PM_{10} and CO Concentrations at Session Road Station

Preliminary data from the first day of sampling including real-time PM and CO data at the Session Road monitoring station and traffic observations within the CBD were used in the selection of sampling periods within the street-level study. The sampling periods were selected to capturing two high and one moderately low PM and CO concentration periods. Figure 4-3 shows the real-time $PM_{2.5}$, PM_{10}, and CO concentrations at the Session Road monitoring station throughout the entire monitoring period (n=11 days). $PM_{2.5}$ and PM_{10} were highly correlated ($r = 0.992$) while moderately strong correlations were seen between $PM_{2.5}$ and CO ($r = 0.764$) and PM_{10} and CO ($r = 0.810$). The two highest peaks correspond to the morning and afternoon rush hours.

The early morning monitoring period (4:50-6:30am) was originally chosen as the first street-level monitoring period because of its low automotive and commercial activities, but the real-time data at the fixed station shows that PM and CO concentrations start to increase as early as 3AM and peak between 6-7AM, therefore making the early monitoring period a poor baseline. The afternoon monitoring period (3:40-5:40PM) took place during the first part of the afternoon rush but did not cover the period where the pollutants were maximal (6-8PM) due to safety issues after sunset.

Street-level $PM_{2.5}$, PM_{10} and CO Averages Throughout the Street Site Study

Table 4-4 shows the average, maximum and minimum real-time $PM_{2.5}$, PM_{10} and CO measurements among the 30 sites within each time period during the street-level characterization study. Although there was about twice as many gasoline and diesel-powered automobiles during rush hours compared to the earliest period, the $PM_{2.5}$ and PM_{10} mean concentrations among the 30 sites were not statistically different among the three monitoring periods (all p-values >.450 using least squares distance (LSD) tests). However, CO concentrations statistically differed among the 30 sites between early morning and morning rush hour ($p = 0.039$) and early morning and afternoon rush hour ($p = 0.007$). The early morning, morning rush hour and afternoon rush hour average street-level $PM_{2.5}$ concentrations were 110, 98 and 107 $\mu m/m^3$, respectively, while the PM_{10} averages were 118, 124 and 117 $\mu m/m^3$, respectively. The average CO concentrations during these three periods were 3.0, 4.1 and 4.5 ppm, respectively.

Multiple Regression Modeling

Results of the final pooled analyses for each outcome of the multiple regression analysis for ln(CO), ln($PM_{2.5}$) and ln(PM_{10}) appear in Table 4-5 including slope estimates, standard errors, T-statistics and p-values. The explanatory variables within the CO multiple regression model that contained a slope significantly different from zero was ANY_WIND in the early morning (slope of -0.482; $p = 0.044$) and TRAFFIC_PC in both morning rush hour (slope of 0.179; $p = 0.048$) and afternoon rush hour (slope of 0.204; $p = 0.034$). TRAFFIC_PC was the only significant explanatory variable produced in the $PM_{2.5}$ (slope of 0.542; $p = 0.021$) and PM_{10}

(slope of 0.458; p = 0.048) multiple regression models, and both occurred during the early morning monitoring period.

Pearson Correlations Between Response and Explanatory Variables

Point estimates and 95% confidence intervals for the Pearson correlation between each response variable (ln(CO_AVG), ln(PM10_AVG), or ln(PM25_AVG)) and each continuously scaled explanatory variable used in the regression models (AVG_STORY, ROADSZ_PC, TRAFFIC_PC) are reported in Table 4-6. These are pooled results (i.e., multiply imputed results) based on the 5 imputed data sets. Of the three continuously scaled explanatory variables, TRAFFIC_PC had the highest Pearson correlation among each response variable [ln(CO_AVG) (r = 0.491); ln(PM10_AVG) (r = 0.266); ln(PM2.5_AVG) (r = 0.292)].

Discussion

Ambient Pollution Concentrations

The results of this study indicate that air pollution levels, particularly PM, in Baguio City are elevated in comparison to areas in compliance with ambient air standards. The mean 24-hr $PM_{2.5}$ concentration measured at the Session Road fixed monitoring site was 72.9 $\mu m/m^3$. The Philippines have an established standard for TSP and PM_{10} but not $PM_{2.5}$ (Table 4-7). Compared to the US National Ambient Air Quality Standards (NAAQS) $PM_{2.5}$ standard, the gravimetrically measured 72.9 $\mu g/m^3$ $PM_{2.5}$ concentration is over the maximum 24-hr limit (65 $\mu m/m^3$) and the maximum one-year $PM_{2.5}$ average (15 $\mu m/m^3$) indicating a serious air pollution problem. While five of the eleven total days of sampling were over the 24-hr 65 $\mu m/m^3$ limit, all these days

occurred within the first half of the study (Dec. 14-19) and the ambient $PM_{2.5}$ concentration progressively decreased throughout the study as Christmas approached. This decrease is believed to be due to less pedestrian and automotive traffic within the CBD because of increased vacation of Baguio citizens from work and the closings of the schools and colleges within the CBD for the holiday season. The mean 24-hr CO and NO_2 concentrations measured at the Session Road fixed monitoring site were below established Philippine and US air pollution standards and WHO guidelines. The average ambient toluene concentration was slightly higher than the normal ambient urban toluene concentration range (5-150 $\mu m/m^3$) but still below the ambient WHO guideline of 260 $\mu m/m^3$ (WHO, 2000). Also, one of the four field blanks was contaminated with a high concentration of toluene (288 $\mu m/m^3$), therefore decreasing the confidence in the average toluene concentration.

The $PM_{2.5}$, PM_{10} and CO concentrations measured at the Session Road monitoring station were two- to four-fold higher than the concentrations measured at CJH illustrating the potential increase of pollutants due to anthropogenic means. The ambient environment at CJH is generally pristine without any nearby pollution sources while the air at the Session Road station is constantly affected by a variety of pollution sources including motor vehicles, restaurants, bakeries, etc. However, the sample duration was only 36 hours long and contained the only rain of the entire sampling period at both locations (4 hours), therefore possibly making the data not representative of the true environment.

Street-level Pollution Concentrations

Since the street-level concentrations were only 15-minute measurements and two of those three periods were during the rush hours, the average pollutant concentrations for the 45-minutes of monitoring per site would most likely be higher compared to the unmeasured, 24-hr average pollutant concentrations at that site. However, the average $PM_{2.5}$ and PM_{10} concentrations over the three monitoring periods are high enough to be of concern. Sixteen of the 30 sites within the CBD had an average $PM_{2.5}$ during the 45-minutes of sampling over 100 $\mu m/m^3$ (highest of 196 $\mu m/m^3$). Ten of these 16 sites were on either Session Road or Magsaysay Avenue, two of the busiest roads within the CBD. Seven of the 30 sites had a PM_{10} average over 150 $\mu m/m^3$, with one having an average PM_{10} concentration of 287 $\mu m/m^3$. Five of these sites were located on Session Road while the two other was located on Magsaysay Avenue.

Multiple Regression Models and Nocturnal Inversions

Between sunrise (6:15am) and sunset (5:30pm) from December 14-25, the lowest average one-hour $PM_{2.5}$ concentration at the Session Road station was 24.2 $\mu m/m^3$ (10 to 11am) (Figure 4-3). From sunset to sunrise during the same period, the lowest average one-hour $PM_{2.5}$ concentration was 36.0 $\mu m/m^3$ (3-4am). From 3 to 4am there was a much lower automotive population present comparative to the 10-11am period as well as little to no combustion activity taking place in nearby commercial or residential settings. However, the lowest average one-hour $PM_{2.5}$ concentration during the night was 50% higher than the lowest average one-hour $PM_{2.5}$ concentration during the day. This difference in ambient concentrations is most likely due to the presence of regular nocturnal inversions often present within Baguio due to its location within a

mountain basin. These inversions produce a "blanket" of air pollution in the lower atmosphere preventing the vertical mixing of air during the night and therefore increase the stagnation and concentration of the pollutants.

Traffic intensity was only a significant explanatory variable in the early morning for both $PM_{2.5}$ and PM_{10} in the multiple regression modeling. Due to the presence of the nocturnal inversion and the fact that there were relatively few pollution sources other than motor vehicles operating from 4:30-6:30am, the $PM_{2.5}$ and PM_{10} being emitted from automobiles were not diluted optimally, and therefore the pollution remained present for longer periods. Also the presence of wind was a significant variable in the early morning CO concentration (slope of -0.482) because the presence of wind would increase the dilution of CO.

During the morning rush hour period (6:30 – 9:10am) the ambient pollution was composed of multiple sources including automobile exhaust, the remnants of the inversion's "pollution blanket" as it returned to the ground in visible sheets 30 minutes after sunset, and a few commercial and residential point sources. During the afternoon rush hour period (3:40 – 5:40pm) most commercial bakeries, restaurants, etc. were running within the CBD emitting pollution from their cooking practices using natural gas and liquefied petroleum gas (LPG) as well as the automobiles emitting exhaust into the environment.

The selection of the three street-level monitoring periods was not optimal. The nocturnal inversion effect at night prevented the natural dilution of pollution in the atmosphere, and in turn the early morning monitoring period did not contain the lowest pollution concentrations of the day, therefore making it a poor baseline period. The morning rush hour period was heavily affected by the layers of pollution returning to the ground after the breakup of the inversion

layer. The afternoon rush hour did not capture the highest pollution peak (7-8pm) due to safety issues after sunset. However, each sampling period was unique due to their respective scenarios. During the early morning period the automobile density was lowest while commercial and residential settings were mainly inactive. During the morning rush hour automobile densities were high, a large percentage of commercial businesses (e.g. restaurants) in the CBD were not open, and the presence of the inversion breakup added a variable only seen during this time of day. During the afternoon rush hour automobile and commercial businesses were highest of all three periods.

Limitations

The primary limitations of this study include the short sampling time and the interpretation of the DustTrak data. Since ambient sampling took place over 11 days, it does not contain a seasonal effect and is hard to determine whether or not concentrations measured are representative of the annual average. Air pollution concentrations were declining during the second half of sampling due to Christmas, therefore possibly lowering the average concentrations in comparison to a time that saw no holiday effect. Secondly, the use of DustTraks in a variety of settings created a limiting factor. The DustTraks were adjusted according to a concentration ratio created using the data produced by a DustTrak and a gravimetric $PM_{2.5}$ setup collocated at the Session Road station. However, the PM measured three-stories above street-level at the Session Road monitoring station may not be representative to the PM measured at various locations within the CBD or CJH, therefore potentially changing the concentration ratio. Since gravimetric measurements could be not taken at the 30 street-level

monitoring stations, the concentration ratio produced at the fixed monitoring station was used for all locations in the study.

Conclusions

The data suggest that ambient PM levels in Baguio City, Philippines are above Filipino and US EPA daily (65 $\mu m/m^3$) and annual standards (15 $\mu m/m^3$), and as such warrant public health concern. Further, the data suggests that nocturnal inversions play a large role in the nightly PM concentrations within the CBD by limiting the vertical mixing of the lower atmosphere and preventing the dilution of PM and CO. The limited mixing of the atmosphere provide little relief in pollution dilution in a time where pollution sources are less, therefore creating a scenario that may lead to prolonged ambient exposures and health problems.

Future research in Baguio City, Philippines is necessary in order to determine seasonal variation of ambient pollution as well as characterizing personal exposures of air pollution to citizens and tourists. With Baguio's cooler temperatures and many festivals that lure tourists from throughout the country and the world, the potential drop in tourism and the resulting loss of income due to air pollution would be a hardship on the local economy.

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Table 4-1. Street-level explanatory variables.

Variable Name	Variable Description	Scale	Levels
PERIOD	Time of day during which measurements were taken	Nominal	0=Early morning, 1=Morning rush, 2=Afternoon rush
DIES_MIN	Diesel-powered vehicles per minute	Continuous	
AUTOS_MIN	Automobiles (gasoline+diesel) per minute	Continuous	
PEOP_MIN	People per minute (foot traffic)	Continuous	
AVG_STORY	Average number of building stories present in immediate surroundings	Continuous	
ROAD_WIDTH	Width of road in meters from sidewalk to sidewalk	Continuous	
ROAD_LANES	Number of lanes in the road.	Continuous*	
TRAF_FLOW	Traffic flow rating	Ordinal	0=Traffic is moving smoothly, 1=Traffic is moving, but not smoothly, 2=Traffic is backed up.
ANY_WIND	Presence/absence of non-negligible wind.	Dichotomous	0=Wind absent, 1=Wind present
MEDIAN	Presence/absence of a median in roadway.	Dichotomous	0=No Median Present, 1=Median Present
STOP_TRAF	Presence/absence of a stop sign/light, traffic cop, or other means to stop traffic	Dichotomous	0=Absent, 1=Present
UPWIND_SOURCE	Presence/absence of non-automobile-related upwind pollution sources	Dichotomous	0=Absent, 1=Present
HILL	Presence/absence of hilly terrain	Dichotomous	0=Absent, 1=Present

* These variables are really counts, taking non-negative integer values, but are treated as continuous in the analyses.

Table 4-2. Results of explanatory variable clustering.

Cluster	Original Variables in the Cluster	Variables Representing the Cluster in Analyses
1	AUTOS_MIN DIESEL_MIN GAS_MIN PEOPLE_MIN STOP_TRAF TRAF_FLOW	TRAFFIC_PC
2	ROAD_LANES ROAD_WIDTH MEDIAN	ROADSZ_PC
3	AVG_STORY	AVG_STORY
4	HILL	HILL
5	ANY_WIND	ANY_WIND
6	UPWIND_SOURCE	UPWIND_SOURCE

Table 4-3. 24-Hour Pollutant Average at Session Road Monitoring Station.

Pollutant	Unit	# of sample days	Average ± St. Dev	Max	Min
$PM_{2.5}$ (Harvard Impactor)	$\mu g/m^3$	11	72.9 ± 21.2	124.4	46.7
PM2.5 (DustTrak)$^+$	$\mu g/m^3$	8	67.0 ± 28.2	117.5	43.0
PM10 (DustTrak)$^+$	$\mu g/m^3$	8	80.1 ± 28.0	127.9	56.8
CO	ppm	11	2.64 ± 0.6	3.6	1.4
NO_2*	ppb	11	27.7 ± 1.6	26.1	29.7
Benzene*	$\mu g/m^3$	11	8.4 ± 1.4	9.9	6.9
Toluene*	$\mu g/m^3$	11	173.7 ± 100.9	277.6	58.6
Ethylbenzene*	$\mu g/m^3$	11	4.6 ± 2.0	6.6	1.9
P-xylene*	$\mu g/m^3$	11	4.4 ± 1.9	6.3	1.8
M-xylene*	$\mu g/m^3$	11	10.2 ± 4.4	14.8	4.7
O-xylene*	$\mu g/m^3$	11	7.5 ± 3.2	10.8	3.4

$^+$Complete 24-hr data from only 8 out of 11 days due to equipment problems
* Each samples ran for a 72-hour period

Table 4-4. Real-time $PM_{2.5}$, PM_{10} & CO and automobile counts for street-level 15-minute measurements at 30 sites.

		$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	CO (ppm)	Gasoline autos/min	Diesel autos/min
Early Morning (4:50 - 6:30AM)	Average	126	136	3.0	2.5	10.4
	St. Dev	9	9	1.7	1.6	6.5
	Maximum	276	312	5.3	5.0	23.1
	Minimum	57	62	1.9	0.0	0.1
Morning Rush Hour (6:30 - 9:10AM)	Average	112	142	4.1	6.6	18.7
	St. Dev	8	13	2.3	3.9	9.5
	Maximum	314	63	9.8	20.9	41.9
	Minimum	49	55	2.2	0.3	0.9
Afternoon Rush Hour (3:40 - 5:40PM)	Average	122	135	4.5	6.6	20.5
	St. Dev	6	7	2.2	3.8	10.6
	Maximum	329	345	11.2	18.0	44.1
	Minimum	54	60	2.4	0.1	1.8

Table 4-5. Multiple regression model results for ln (CO), ln($PM_{2.5}$) and ln(PM_{10})

			ln(CO)				ln($PM_{2.5}$)				ln(PM_{10})			
Para-meter	**Period**	**Parameter Description**	**Slope Estimate**	**St. Error**	**T Stat**	**p-value**	**Slope Estimate**	**St. Error**	**T Stat**	**p-value**	**Slope Estimate**	**St. Error**	**T Stat**	**p-value**
β_{01}	1	Intercept	1.589	0.346	4.59	**0.000**	-1.066	0.390	-2.73	**0.014**	-1.119	0.391	-2.86	**0.011**
β_{11}	1	TRAFFIC_PC1	0.306	0.190	1.61	0.126	0.542	0.213	2.54	**0.021**	0.458	0.214	2.14	**0.048**
β_{21}	1	ROADSZ_PC1	0.093	0.130	0.71	0.485	0.019	0.147	0.13	0.898	0.026	0.147	0.18	0.860
β_{31}	1	AVG_STORY	0.042	0.135	0.31	0.757	0.144	0.153	0.94	0.361	0.121	0.153	0.79	0.440
β_{41}	1	HILL	0.072	0.275	0.26	0.796	-0.059	0.314	-0.19	0.853	-0.015	0.312	-0.05	0.962
β_{51}	1	ANY_WIND	-0.482	0.221	-2.18	**0.044**	-0.270	0.246	-1.10	0.287	-0.156	0.248	-0.63	0.538
β_{61}	1	UPWIND_ SOURCE	0.201	0.293	0.68	0.503	0.289	0.325	0.89	0.386	0.246	0.327	0.75	0.462
β_{02}	2	Intercept	1.034	0.489	2.11	**0.049**	-1.392	0.558	-2.50	**0.024**	-1.430	0.637	-2.25	**0.048**
β_{12}	2	TRAFFIC_PC1	0.179	0.084	2.13	**0.048**	0.137	0.094	1.45	0.164	0.085	0.096	0.89	0.389
β_{22}	2	ROADSZ _PC1	-0.073	0.111	-0.66	0.519	-0.046	0.127	-0.36	0.723	-0.006	0.133	-0.04	0.967
β_{32}	2	AVG_STORY	0.131	0.133	0.99	0.338	0.012	0.153	0.08	0.937	0.147	0.150	0.98	0.342
β_{42}	2	HILL	0.246	0.320	0.77	0.453	0.125	0.370	0.34	0.739	-0.749	0.588	-1.27	0.233
β_{52}	2	ANY _ WIND	-0.387	0.444	-0.87	0.395	-0.769	0.510	-1.51	0.152	0.080	0.370	0.22	0.832
β_{62}	2	UPWIND_ SOURCE	0.107	0.216	0.49	0.628	0.293	0.245	1.20	0.249	0.158	0.249	0.63	0.536

β_{03}	3	Intercept	0.864	0.370	2.34	**0.032**	-1.723	0.413	-4.17	**0.001**	-1.546	0.414	-3.73	**0.002**
β_{13}	3	TRAFFIC_PC1	0.204	0.089	2.30	**0.034**	0.140	0.098	1.43	0.172	0.127	0.099	1.28	0.218
β_{23}	3	ROADSZ _PC1	-0.093	0.113	-0.83	0.420	-0.113	0.126	-0.90	0.381	-0.093	0.126	-0.73	0.473
β_{33}	3	AVG_STORY	0.096	0.119	0.80	0.434	-0.024	0.135	-0.18	0.862	-0.022	0.135	-0.16	0.871
β_{43}	3	HILL	0.088	0.291	0.30	0.766	-0.005	0.328	-0.02	0.987	0.003	0.327	0.01	0.994
β_{53}	3	ANY _ WIND	0.024	0.256	0.09	0.927	0.149	0.279	0.53	0.601	0.069	0.286	0.24	0.812
β_{63}	3	UPWIND_ SOURCE	-0.046	0.282	-0.16	0.873	-0.148	0.313	-0.47	0.642	-0.164	0.315	-0.52	0.610

Table 4-6. Pearson correlation estimates and 95% confidence intervals for association between the continuous explanatory variables and the response variables in the multiple regression models.

Explanatory Variable	Test	Ln(CO_AVG)	Ln(PM10_AVG)	Ln(PM2.5_AVG)
TRAFFIC_PC1	Pearson Correlation (r)	0.491	0.266	0.292
	95% CI	(.316,.634)	(.063,.449)	(.090,.471)
ROADSZ_PC1	Pearson Correlation (r)	0.255	0.248	0.226
	95% CI	(.050,.439)	(.043,.433)	(.019,.414)
AVG_STORY	Pearson Correlation (r)	0.227	0.149	0.063
	95% CI	(.021,.415)	(-.060,.346)	(-.146,.267)

Table 4-7. Philippines and US ambient air quality standards and WHO guidelines.

POLLUTANT	AVERAGING TIME	Philippines[o]	US National Ambient Air Quality Standards[+]	World Health Organization[#]
Total suspended particulates (TSP)	24-hour	230 µm/m^3	N/A	**
	1-year	90 µm/m^3	N/A	**
PM10	24-hour	150 µm/m^3	150 µm/m^3	**
	1-year	60 µm/m^3	50 µm/m^3	**
PM2.5	24-hour	N/A	65 µm/m^3	**
	1-year	N/A	15 µm/m^3	**
Nitrogen dioxide	24-hour	0.08 ppm (150 µm/m^3)	N/A	N/A
	1-year	N/A	0.053 ppm (100 µm/m^3)	0.021 ppm (40 µm/m^3)
Carbon Monoxide	1-hour	31 ppm (35mg/m^3)	35 ppm (40mg/m^3)	26 ppm (30mg/m^3)
	8-hours	9 ppm (10mg/m^3)	9 ppm (10mg/m^3)	9 ppm (10mg/m^3)

** WHO no longer recommends air quality guidelines for PM because there is no safe lower limit

Sources: [o]Philippines Clean Air Act of 1999; [+]US CFR Title 40, Part 50

[#]WHO Air Quality Guidelines for Europe (2000)

Figure 4-1. Location of Baguio City, Philippines

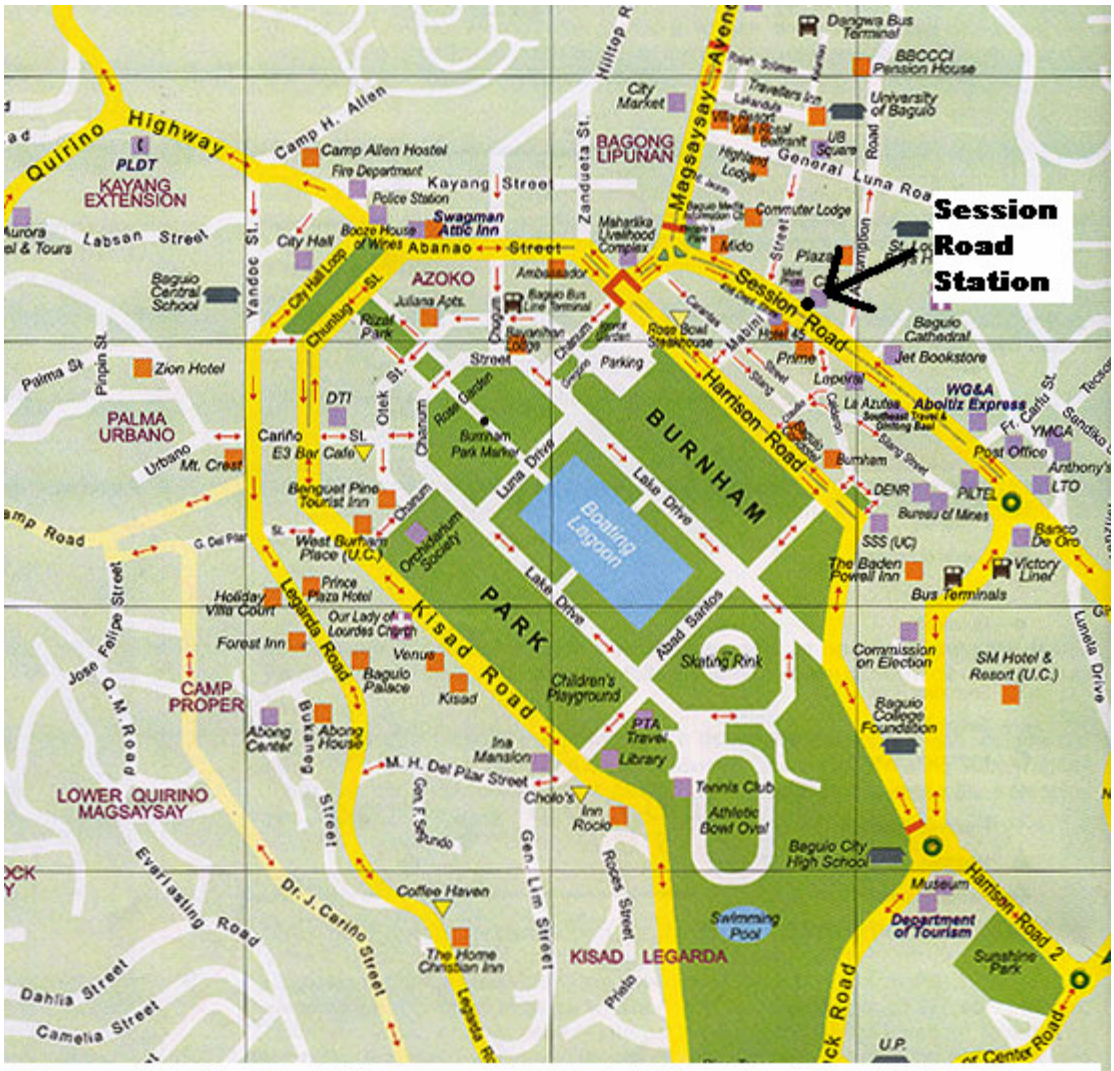
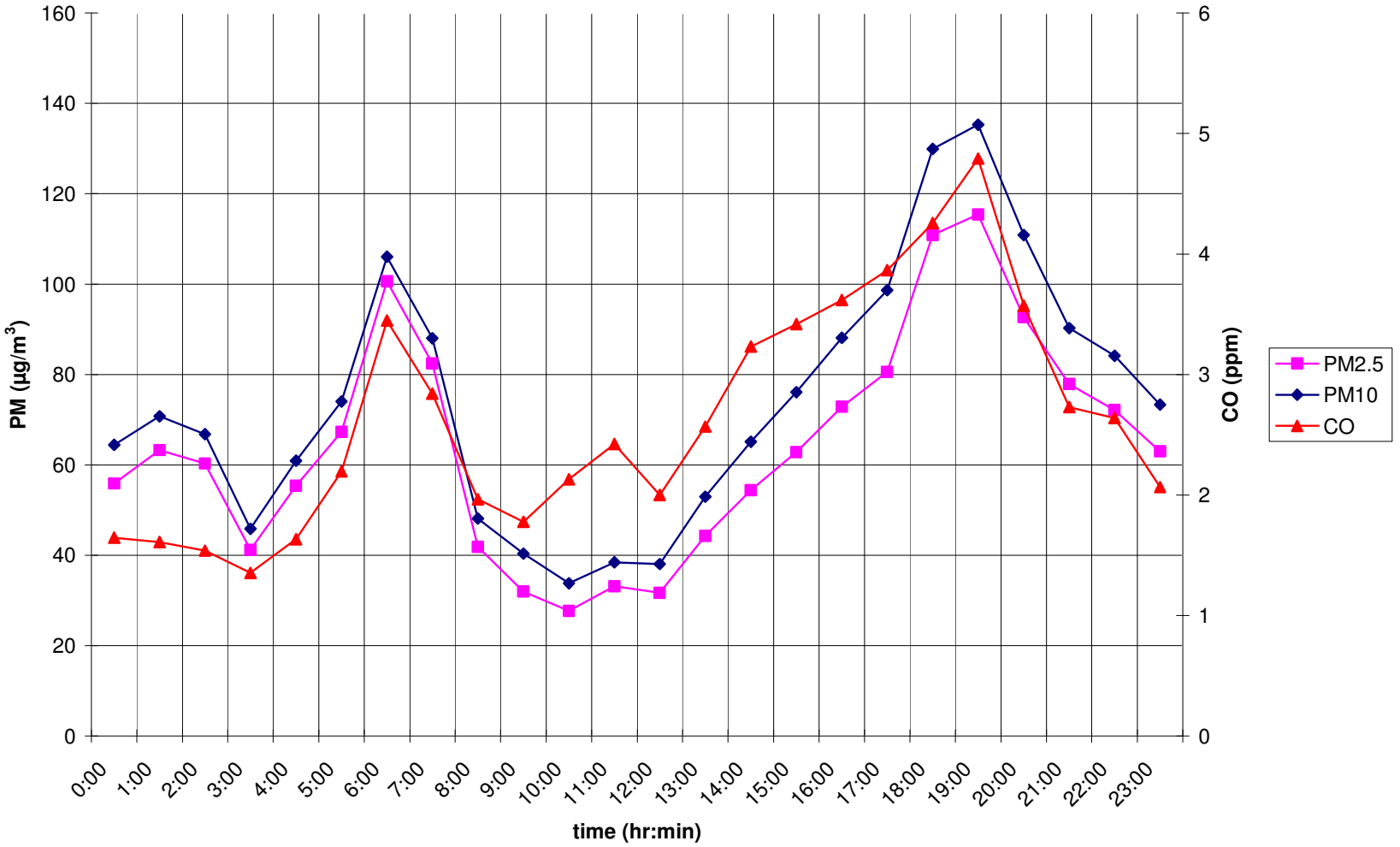


Figure 4-2. Central Business District of Baguio City, Philippines

Figure 4-3. Average PM2.5, PM10 and CO Concentrations at Session Road Fixed Station



CHAPTER 5

CONCLUSIONS

$PM_{2.5}$, CO, NO_2 and select VOCs at fixed monitoring stations in urban and rural Trujillo, Peru during periods of varying traffic densities

The results of this study suggest that ambient $PM_{2.5}$ levels in urban and rural Trujillo are consistently above the annual Peruvian and US EPA ambient air quality standards, and as such warrant public health concern. The mean $PM_{2.5}$ concentrations measured during both seasons and at both monitoring stations were approximately twice the concentration of the USEPA NAAQS and the Peruvian National Ambient Air Standards annual $PM_{2.5}$ limit. However, only nine weeks of ambient $PM_{2.5}$ measurements were collected in the current study so it is not possible to definitively determine if Trujillo is in compliance with these annual $PM_{2.5}$ standards. However, if the concentrations observed in the current study remained relatively constant throughout the year, the annual $PM_{2.5}$ standards would be exceeded.

Ambient NO_2 and CO concentrations measured at both locations and during both seasons did not exceed either NAAQS or Peruvian National Standards.

Mean pollutant concentrations were generally higher at Trujillo City Hall than at the Trujillo airport primarily due to the closer proximity to motor vehicles as well as commercial, industrial and residential establishments opposed to the area surrounding the Trujillo Airport.

Mean pollutant concentrations were generally higher during the July/August period than during the October/November monitoring period. These trends indicate that seasons and/or seasonal fossil fuel combustion use may play a role in pollution concentrations within Trujillo. However, due to a lack of seasonal information on roadway density, agricultural field burning and commercial/industrial/residential

pollution emission in the current study, we can not definitely say whether the changing pollution concentrations are primarily due to a seasonal climate change, a change in ambient pollution input, or a combination of both.

The "*Dia Sin Autos*" natural experiment illustrated that street-level $PM_{2.5}$ concentrations are reduced by 50% and ambient $PM_{2.5}$ concentrations are reduced by 25% when nearby motor vehicle traffic is removed.

The findings of this study show that PM concentrations in the downtown area are elevated enough to be of concern to public health. $PM_{2.5}$ concentrations were consistently out of compliance at both urban and rural monitoring stations during both monitoring seasons. Motor vehicle traffic was shown to play a significant role, and its contribution was partly seen during the "*Dia Sin Autos"* experiment where ambient $PM_{2.5}$ concentrations decreased 25% when automobiles weren't present within the *Avenida España* perimeter surrounding the downtown area (at least 430 meters from the monitoring station).

Ambient and street-level pollution concentrations during different period of day in Baguio City, Philippines

The results of this study suggest that average ambient $PM_{2.5}$ levels in Baguio City, Philippines (72.9 $\mu m/m^3$) are regularly above daily (65 $\mu m/m^3$) and consistently above annual (15 $\mu m/m^3$) Filipino and US EPA air pollution standards, and as such warrant public health concern. However, only two weeks of ambient $PM_{2.5}$ measurements were collected in the current study so it is not possible to definitively determine if Baguio City is in compliance with the annual $PM_{2.5}$ standards. However, if the concentrations

observed in the current study remained relatively constant throughout the year, the annual $PM_{2.5}$ standards would be exceeded. All ambient air pollutants other than PM that were measured were below established Filipino and US EPA standards and WHO guidelines.

All pollutants measured at the fixed-site ambient pollution monitoring station (Session Road station) using real-time equipment ($PM_{2.5}$, PM_{10} and CO) showed a fluctuation pattern throughout the day similar to nearby automobile density. Real-time concentrations measured throughout the night decreased accordingly to the lack of pollution sources, but remained at a slightly increased state due to the nocturnal inversions present.

Multiple regression modeling showed that traffic intensity was a significant variable for early morning $PM_{2.5}$ and PM_{10} as well as morning and afternoon rush hour CO. Early morning wind patterns were significant with early morning CO concentrations. The inverse relationship between CO and wind illustrate that during morning periods containing wind, the wind assists in the dilution of CO.

Traffic intensity had the highest Pearson correlation among each street-level continuous response variable measured at the 30 sites within downtown Baguio City [$\ln(CO)$ $r = 0.491$; $\ln(PM_{10})$ $r = 0.266$; $\ln(PM_{2.5})$ $r = 0.292$].

The findings of this study show that PM concentrations in the downtown area of Baguio City are elevated enough to be of concern to public health. $PM_{2.5}$ concentrations were consistently above daily and annual $PM_{2.5}$ limits. Motor vehicle traffic was shown to play a significant role with $PM_{2.5}$ and PM_{10} early in the morning and CO during morning and afternoon rush hour.

Thesis summary

Air pollution is a major problem affecting billions of people throughout the world. No person, rich or poor, is immune to the potential harmful effects associated with exposures to air pollution. From the coastal cities of Peru to the mountainous cities of the Philippines, people are being exposed to harmful chemicals with each breath they take.

Table 5-1 compares the ambient $PM_{2.5}$ concentrations measured in the two studies described in chapters 3 and 4 to a handful of other studies that have taken place throughout the world. The average $PM_{2.5}$ concentration measured in Baguio City, Philippines is higher than all average ambient concentrations except for the concentrations measured in Beijing, China. Although the average $PM_{2.5}$ concentration measured in Trujillo is above established US and Peruvian annual $PM_{2.5}$ standards, it is not common to find concentrations similar to these throughout the world, particularly within the cities of developing countries.

Although the inventions of newer technologies with lower pollution emission rates have become available over the years, it is usually only the developed countries that can afford to incorporate these new technologies while the developing countries must resort to using older methods that emit more pollution. In turn the ambient pollution concentrations within cities of the developing countries are often higher than those seen in developed country's cities.

It is often seen in the developing world that the natives know that there is a problem, but do not have any means to better their situation. Although these people may vary in race, culture and religion, and their homes may be as different as a sea-level, arid Peruvian city and a mountainous, monsoon-ridden Filipino city, all of these people are

human beings and their exposures to hazardous ambient air pollution can affect their health equally.

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Table 5-1. $PM_{2.5}$ concentrations measured in various studies throughout the world.

Citation	**Sampling Period**	**Sampling Location**	**Average $PM_{2.5}$ ($\mu g/m^3$)**
Chapter 3	July - August & October - November 2003	Trujillo, Peru	29.3 ± 10.2
Chapter 4	December 2004	Baguio City, Philippines	72.9 ± 21.2
Yang et al.	July 1999 - June 2000	Beijing, China	116
Chan et al.	August 2003	Beijing, China	93.6
Fang et al.	March 2004 - January 2005	Taichung Harbor, Taiwan	54.03 ± 16.92
Naeher et al.	May - June 2004	Arequipa, Peru	46.4 ± 21
Shendell et al.	May - June 1997	Guatemala City, Guatemala	37.9 ± 21.5
Vassilakos et al.	April - November 2003	Athens, Greece	21.1
Götschi et al.	June 2000 - December 2001	Turin, Italy	44.9 ± 22.5
		Barcelona, Spain	22.2 ± 7.6
		Paris, France	17.8 ± 6.9
		Reykjavik, Iceland	3.7 ± 1.7