EnvironmentAsia
The international journal published by the Thai Society of Higher Education Institutes on Environment

Available online at www.tshe.org/EA
EnvironmentAsia 5(2) (2012) 11-15

Temporal Characteristics of Airborne Particulate Matter in Phnom Penh, Cambodia

Joel D. Bernosky and Stephen J. Vermette

Department of Geography and Planning, Buffalo State College, State University of New York, 1300 Elmwood Avenue, Buffalo, NY 14222, U.S.A.

Abstract

Particulate matter of less than 10 microns (PM-10), has been identified as a critical airborne pollutant of most Asian cities, and is often attributed to vehicle traffic. PM-10 is not routinely monitored in Phnom Penh, Cambodia. Using a particle counter, PM-10 was monitored along Phnom Penh roads creating road-side temporal profiles. The 'commuter profile' exhibited high PM-10 counts in the morning and late afternoon. The 'business district profile' exhibited high PM-10 counts in the late-morning/early-afternoon. The PM-10 particle counts were converted to PM-10 mass measurements (μg/m^3). The PM-10 mass measurements exceeded the WHO daily standard of 50 μg/m^3, while it approached and sometimes exceeded (during periods of peak traffic) the U.S. EPA standard of 150 μg/m^3.

Keywords: PM-10; Phnom Penh, Cambodia

1. Introduction

The city of Phnom Penh (13ºN, 105ºE) (Fig. 1) is located in south-central Cambodia, to the west of the confluence of the Bassac, Mekong and Tonle Sap rivers. Possessing a population of over 1.5 million, Phnom Penh covers approximately 375 square kilometers (Planning, 2004).

As Cambodia's capital city, and with a growing national GDP, Phnom Penh is currently undergoing heavy development and population expansion and expanding its boundaries into the surrounding rural farmland and wetlands. This expansion carries with it increased energy and resource use as well as increased vehicles and traffic, as well as air pollution (Furuuchi *et al*., 2006). Particulate pollution is a significant problem, as residents are often seen wearing surgical-type masks while on the streets and many visitors to Phnom Penh remark on the dust levels. CAI-Asia (2010) has identified particulate matter, with an aerodynamic particle diameter of 10 microns or less (PM-10), as a critical pollutant for most Asian cities. Currently, PM-10 is not routinely monitored in Phnom Penh (Cambodia, 2006; CAI-Asia, 2010), although there are a number of ad hoc studies that have reported Total Suspended Particulates (TSP) or PM-10 concentrations (Kashima *et al*., 2001; Furuuchi *et al*., 2006). Respiratory diseases are believed among the leading causes of morbidity in Cambodia (Cambodia, 2006). While there are currently no Cambodian studies to support a link between PM-10 and respiratory disease, there are numerous examples establishing such links in other cities (Pope and Dockery, 2006; Brunekreef and Forsberg, 2005).

The streets of Phnom Penh are busy with traffic and numerous roadside businesses are open to the street. Studies in developed countries found areas in the immediate proximity of roads show a very high concentration of particulates (Morawska *et al*., 1999), and a higher risk and mortality rate with proximity to traffic air pollution (Hoek *et al*., 2002; Finkelstein *et al*., 2004; Bylina *et al*., 2005). The objective of this study is to characterize road-side PM-10 concentrations in Phnom Penh at different times of the day.

2. Methods and Materials

Airborne ambient pollution samples were collected between June 15 and 24, 2008, using a laser particle counter. A battery operated one-channel particle counter, capable of measuring ambient particles ≤10 μm (Met One Model 229, manufactured by Met One Instruments, Inc., Oregon, United States) was used to sample air quality. The particle counter was operated for the default one minute sampling period, with a set flow rate of 2.83 L/min (0.00283 m^3/min). Multiple one-minute sampling runs were taken in sequence (usually three samples) and the mean counts were reported in count per cubic meter (count/m^3). Subsequent one-minute samples were taken every half-hour throughout the day to complete the temporal sampling. The particle counters were held at chest height, as this allows the counter to sample air that would likely be inhaled.

Temporal analyses (daily profiles) were obtained at eight locations that were chosen to represent typical Phnom Penh street and intersection traffic. Each sample location is plotted in Fig. 1. Each location chosen for particle counting represents a different urban scenario. Locations were also chosen to obtain an approximate even distribution across the city. Summary statistics (mean, median, and mode) were calculated for each profile, where the number of samples (n value) varied based on the number of samples taken with each profile.

A well-known shortcoming of particle counters is the relative difficulty of comparing particle counts to more standard mass measurements. Because of this, a portable high-volume air sampler (Science Source Air Sampler #15000, manufactured by The Science Source, Maine, United States) was used to sample airborne ambient particulates at the Royal University of Phnom Penh site. The one-channel laser particle counter was employed to sample the air directly above the high volume sampler immediately before and after the high volume sampler was run so that recorded particle counts could be compared to particle mass loadings as collected by the high-volume sampler.

3. Results

3.1. Particle Counts and Particle Mass

Particle mass loadings, derived from the analysis of the high-volume air sampler filters, along with the averaged particle counts, collected from the particle counter, were graphed on a scatter plot. Using the trend line's formula of $y = 2\times10^{-7}(x)$-22.82 it is possible to predict the mass represented by a specific particle

Figure 1. Sampling Sites in Phnom Penh

count. Because high-volume air samplers collect Total Suspended Particles (TSP) samples, rather than the PM-10 data collected by the particle counters, it is useful to further convert the data from TSP measurements to PM-10. Kashima *et al*., (2001) sampled both TSP and PM-10 (n= 8), during the month of June, at two sites in Phnom Penh. The PM-10/TSP ratios were tight, ranging from 0.81 to 0.88. By multiplying the TSP measurements obtained in this study by an average ratio of 0.845, PM-10 values were calculated for the city of Phnom Penh.

The temporal profiles show both particle counts and particle mass (PM-10) which is the preferred measurement unit of airborne particles in Environmental Protection Agency (EPA) and World Health Organization (WHO) standards. The EPA standard for PM-10 is a daily average of 150 µg/m^3 (40CFR 50.6(a)) or 8.64x10^8 particle counts/m^3 (our calculation) The WHO standard for PM-10 is a daily average of 50 µg/m^3 (CAI-Asia, 2010) or 3.64x108 particle counts/m3 (our calculation).

3.2. Particle Count/Mass Profiles

3.2.1. Commuter Signature

The longest roadside temporal profile was monitored on June 15, 2008 at Monivong Boulevard, located at the Comfort Star Hotel (Fig. 2a). The mean particle count for this sample site was 8.48x10^8 particles/m^3 with a median count of 8.28x10^8 particles/m3 and a similar standard deviation of 8.28x10^8 particles/m^3. Particles were counted in half-hour increments from 0500 to 1900 hours, incorporating morning, afternoon and evening traffic flow. PM_{10} levels rose above a base count of 6.95x10^8 particles/m^3 through the morning, reaching a peak of 1.21x10^9 particles/m^3 at 1000 hours (an increase in particles of 73% over a 3.5-hour period). With some fluctuation the counts leveled out for a few hours. The particle counts trend downward through the day, hitting a low count of just 5.24x10^8 particles/m^3. A late afternoon increase in particle counts was observed at 1700 hours, peaking at 9.52x10^8 particles/m^3, and lasting only a few hours before returning to a base level of 5.05x10^8 particles/m^3.

The profile taken along Russian Boulevard (Fig. 2b) was very similar to the counts taken previously on Monivong Boulevard (Fig. 2a). The 0900 hour counts were among the highest of the day (6.72x10^8 particles/m^3), with an exception occurring at 1400 hours (7.14x10^8 particles/m^3), followed by a decrease of 69% in particle counts until 1600 hours when levels reached 4.62x10^8 particles/m^3.

The waterfront temporal profile (Fig. 2c) showed a mean particle count that was 5.50x10^8 particles/m^3 with a median count of 6.11x10^8 particles/m^3 and a standard deviation of $2.49x10^8$ particles/m^3. As seen in Fig. 2c, temporal particle counts recorded at the waterfront showed a general decline in particulate levels throughout the day until 1430 hours, from $7.79x10^8$ to $4.29x10^8$ particle/m^3 (a decrease of 55%).

The highest particle counts were measured first thing in the morning. The early counts on Russian Boulevard and along the waterfront likely showed the back-end of the morning commute traffic and terminate prior to the expected late afternoon rise in counts. The spike at 1400 hours (Fig. 2b) appeared to be short-lived and may be indicative only of a short-lived source.

These three locations (Figs. 2) represent a commuter pattern. Vehicles entering the city in the morning (0500 hours) cause particle counts to rise until a peak is reached (0900 to 1000 hours). The evening rush hour traffic at this location was seen when particle count levels again rose from 1600 hours to 1730 hours. Monivong Blvd, Russian Blvd and National Highway 5 (waterfront) are major roads linking the countryside to the urban center, reinforcing the interpretation of the particle count trends as a commuter pattern.

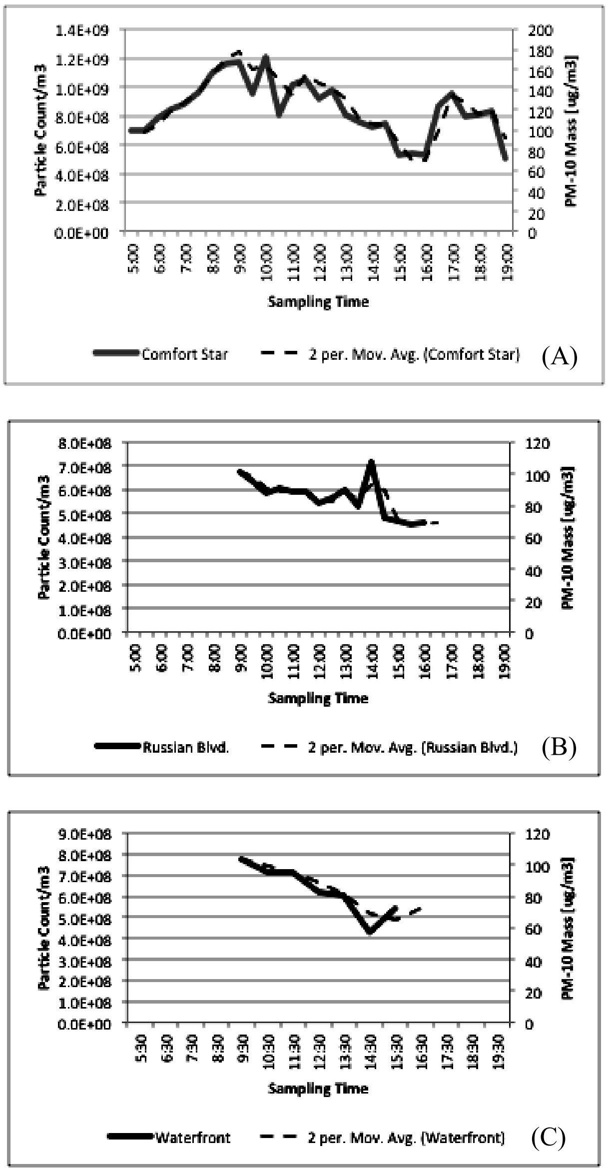

Figure 2. Temporal particle counts for Monivong Boulevard Comfort Star location on June 15, 2008 (A); for Russian Boulevard location on June 17, 2008 (B); and the Waterfront (National Highway 5) on June 20, 2008 (C).

3.2.2. Business District Signature

The temporal profile taken at the Central Market (Fig. 3a) had a mean particle count of $8.64x10^8$ particles/m^3, a median count of $8.24x10^8$ particles/m^3, and a standard deviation of $2.49x10^8$ particles/m^3. The Central Market is a very busy area in the center of Phnom Penh and had high particulate levels in the morning that rapidly dropped from $1.03x10^9$ to $7.24x10^8$ particles/m^3 (900 to 1000 hours), before climbing at midday from $7.37x10^8$ to $9.95x10^8$ particles/m^3 (1100 to 1200 hours), and then dropping again into the afternoon from $1.00x10^9$ to $7.77x10^8$ particles/m^3 (1300 to 1500 hours). The temporal profile of the Central Market differs from that of the commuter pattern (Figs. 2) in that a midday peak is obvious. This peak may represent inner-city traffic based upon a busy shopping and business district that experiences large volumes of traffic in at midday rather than commuter traffic in either the morning or the evening.

The profile taken in East Phnom Penh on Mao Tse Toung Boulevard was similar to that of the Central Market (Fig. 3b). The mean particle count for this sample site was $5.54x10^8$ particles/m^3, with a median count of $5.50x10^8$ particles/m^3, and a standard deviation of $1.43x10^8$ particles/m^3. Mao Tse Toung Boulevard showed a 58% decrease in particle counts from approximately $6.69x10^8$ to $3.90x10^8$ particles/m^3 from 0900 to 0930 hours before they level off for an hour (likely the tail end of the morning rush hour). Particle counts rose 50% from 1030 to 1230 hours (from $3.96x10^8$ to $7.89x10^8$ particles/m^3). Particle counts fell again from 1230 to 1330 hours to $4.44x10^8$ before rising until another peak was reached at 1500 hours (5.70x108). Both patterns (Figs. 3) showed a strong mid-day peak in particle counts suggesting strong mid-day traffic associated with a business district.

3.2.3. Mixed Signatures

Particle counts were taken at the intersection of Russian Boulevard and Street 315 near the Royal University of Phnom Penh, in the Northwest corner of the city. The mean particle count for this sample site was $5.50x10^8$ particles/m^3, with a median count of $5.21x10^8$ particles/m^3, and a standard deviation of $1.35x10^8$ particles/m^3. Recorded from 0900 to 1530

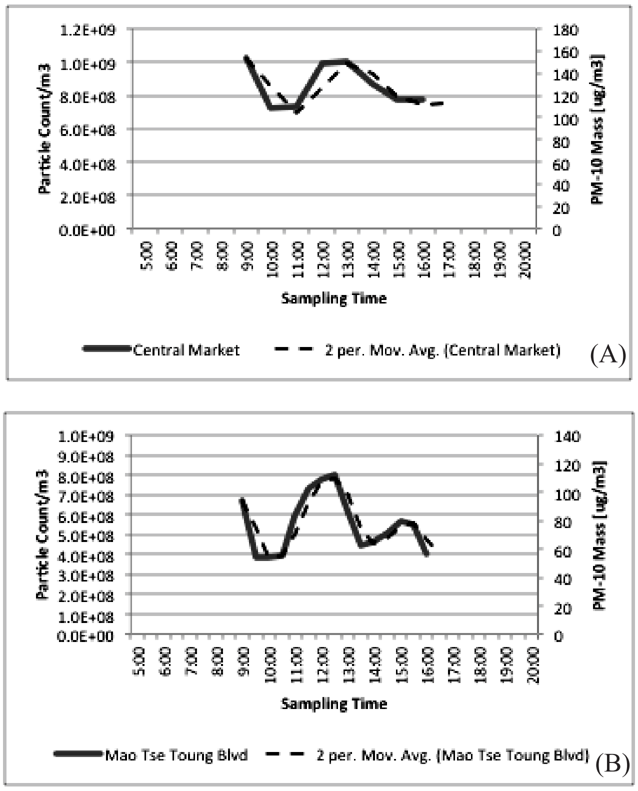

Figure 3. Temporal particle counts for the Central Market on June 20, 2008 (A); and along Mao Tse Toung Blvd on June 21, 2008 (B)

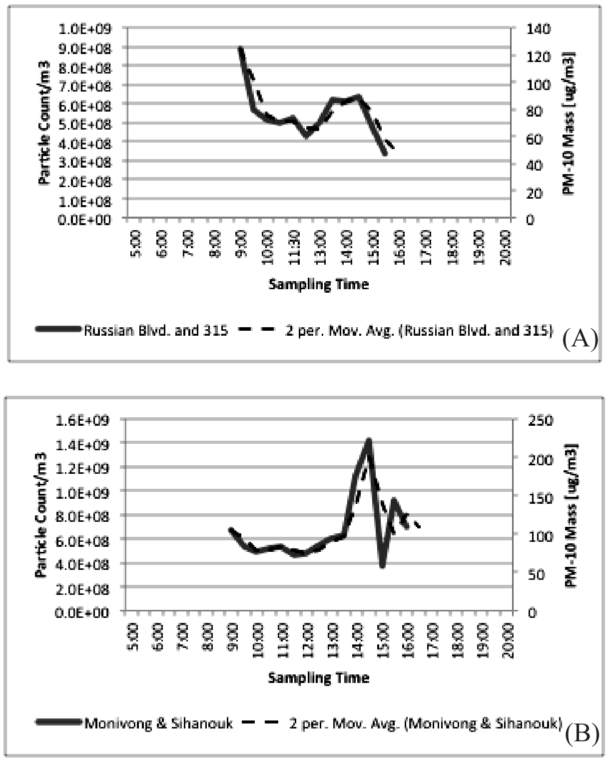

Figure 4. Temporal particle counts for Russian Blvd and Street 315 on June 24, 2008 (A); and at the intersection of Monivong & Sihanouk Blvds on June 19, 2008 (B).

hours the profile, as shown in Fig. 4a, displays a morning commuter pattern, where the 0900 hours sample counts captured the tail end of the morning commute traffic ($8.87x10^8$ particles/m^3). Subsequent sample counts fell until 1300 hours ($4.29x10^8$ particles/m^3), hereafter a second peak in particle counts was observed. An early afternoon increase in particle counts commute traffic clearly defined as an increase (1300 hours to 1500 hours) followed by a decrease in particulate counts. This location clearly showed an early afternoon rush hour typical of a business district signature, although occurring later in the afternoon. The rise in particle counts in the afternoon may signify an earlier occurrence of the evening commute.

The profile taken at the intersections of Monivong and Sihanouk Boulevard (Fig. 4b) showed a mean particle count for this sample site of $6.69x10^8$ particles/m^3, with a median count of $5.83x10^8$ particles/m^3, and a standard deviation of $2.83x10^8$ particles/m^3. The 0900 hour count ($6.72x10^8$ particles/m^3) may represent a decrease from possibly higher rush-hour counts. The particle counts appeared to have stabilized at an average of $5.77x10^8$ particles/m^3 throughout the morning, from 1000 hours to 1330 hours. Through the early afternoon, there appeared to be a fluctuation in counts, including a particle count spike of 74% from 1330 to 1400 hours ($6.29x10^8$ to $1.13x10^9$ particles/m^3). As with Fig. 4a, the afternoon pattern may reflect heavy mid-day traffic, typical of a business district signature, although later in the afternoon.

3.2.4. Unique Signatures

One profile offered a signature that was unique from either the Commuter or Business District profiles, or mixed combinations. The Olympic Stadium sample profile (Fig. 5) showed a mean particle count of $4.30x10^8$ particles/m^3, with a median count of $3.66x10^8$ particles/m^3, and a standard deviation of $2.10x10^8$ particles/m^3. Particulate levels from 0900 hours to 1700 hours fluctuated between around $3.0x10^8$ and $8.08x10^8$ particles/m^3. Particle concentrations at the end of the sampling period (1830 hours) were 37% higher than those seen at the start of sampling (0900 hours). The morning commute signature was absent, and while particle counts fluctuated through the day, there was a clear increase in particle counts through the evening suggesting either a long lived evening commute or greater activity on site in the late afternoon and evening hours.

4. Conclusion

Different traffic patterns existed at different times of the day, and were encompassed in four temporal

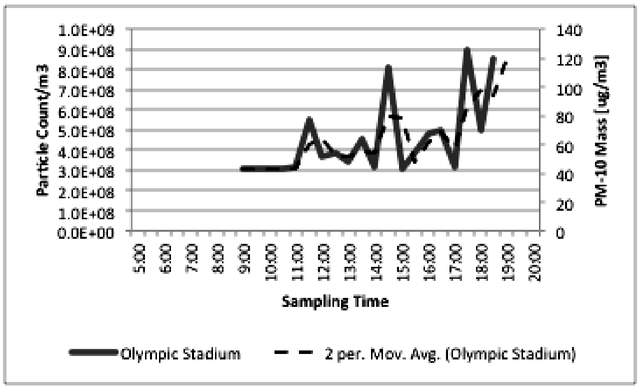

Figure 5. Temporal particle counts for the Olympic Site on June 22, 2008

profile signatures. The first signature was a typical 'Commuter' profile, with high particle count values in the morning and late afternoon, as seen at the Monivong Blvd and Russian Blvd locations (Fig. 2). These two locations are situated near the edge of the city, and serve as commuting roads bringing vehicles in and out of the city center. A second signature, defined as 'Business District', exhibits high PM-10 counts near the middle of the day reflecting heavy mid-day traffic. This pattern was seen at the Central Market and along Mao Tse Toung Blvd (Fig. 3). A third signature appears a mix between the 'Commuter' and 'Business District' signatures. This pattern was seen at the intersection of Russian Blvd and Street 315, and at the intersection of Monivong and Sihanouk Blvds (Fig. 4). The fourth signature group was actually two unique profiles. The Olympic Stadium site exhibited low particle counts in the morning but increasing counts through the afternoon and evening. This profile suggests either an evening commute or greater activity on site in the late afternoon and evening hours The Waterfront site exhibited decreasing particle counts from that of a morning high. This decrease in counts may be attributed to increased wind speeds off of the Mekong River.

Mean particle counts, taken at the eight locations in Phnom Penh, were 6.33×10^8 particles/m^3. This average is slightly higher than the average reported by Vermette *et al*. (2011) for city-wide coarse particles (1.07×10^8 particles/m^3), but it has been reconstructed from averages recorded while taking particle count temporal profiles at mainly busy intersections with limited spatial variability. The mass/volume measurements, in all cases, exceeded the WHO PM-10 daily standard of 50 $\mu g/m^3$, and approached the EPA PM-10 daily standard of 150 $\mu g/m^3$, exceeding the EPA standard during periods of peak traffic.

References

Brunekreef B, and Forsberg B. Epidemiological Evidence of Effects of Coarse Airborne Particles on Health, European Respiratory Journal 2005; 26(2): 187-88.

Bylina BG, Rakwic B, Pastuszka JS. Assessment of Exposure to Traffic-Related Aerosol and to Particle-Associated PAHs in Gliwice, Poland. Polish Journal of Environmental Studies 2005; 14(1): 117-23.

CAI –Asia. Air Quality in Asia: Status and Trends, Clean Air Initiative for Asian Cities Center, Pagig City, Philippines 2010.

Cambodia. Country Synthesis Report on Urban Air Quality Management – Cambodia. Discussion Draft, December, 2006. Prepared by Asian Development Bank and the Clean Air Initiative for Asian Cities (CAI-Asia) Center, 2006.

Furuuchi M, Murase T, Yamashita M, Oyagi, Sakai K, Tsukawaki S, Sieng S, Hata M. Temperature and Air pollution in Phnom Penh, Cambodia – Influence of Land Use and the Mekong and Tonle Sap Rivers. Aerosol and Air Quality Research 2006; 6(2):134-49.

Hoek G, Brunekreef B, Goldbohm S, Fischer P, van dan Brandt PA. Association Between Mortality and Indicators of Traffic-related Air Pollution in the Netherlands: A Cohort Study. Lancet 2002; 360(9341): 1203-09.

Kashima Y, Sakai A, Matsui M, Tsuchiya M. Concentrations of NO2, SO2 and Suspended Particulates in Phnom Penh, Cambodia, Proceedings of the 10th Meeting of the Society of Environmental Science, Matsuyama, Japan 2001; 396-97.

Morawska L, Thomas S, Gilbert D, Greenaway C, Rijnders E. A Study of the Horizontal and Vertical Profile of Submicrometer Particles in Relation to a Busy Road. Atmospheric Environment 1999; 33(8): 1261-74.

Planning Department of Phnom Penh Municiality. 2004. Profiles of Phnom Penh City. 1 Dec. 2008, http://www.phnompenh.gov.kh/english/PhnomPenh_Profile/E_PP_profile.pdf

Pope CA, Dockery DW. Health Effects of Fine Particulate Air Pollution: Lines that Connect. Journal of the Air & Waste Management Association 2006; 56: 709-42.

Vermette SJ, Bernosky JD, Graber Neufeld D. Mapping of Airborne Particulates in Phnom Penh, Cambodia: Comparisons with Bangkok, Thailand and Phoenix, Arizona. Asian Journal of Water, Environment and Pollution 2011; 8(2): 1-9.

Received 4 January 2012
Accepted 22 April 2012

Correspondence to
Joel D Bernosky
Buffalo State College,
Department of Geography and Planning
1300 Elmwood Avenue,
Buffalo, NY 14222
Email: bernjd16@mail.buffalostate.edu