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Commuters' Exposure to Particulate Matter and Carbon Monoxide in Hanoi, Vietnam: A Pilot Study

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Abstract

Urban air pollution continues to be a major problem in Asian cities. Emissions from vehicles are the major contributor to deteriorating air quality in these cities. Most studies of air pollution in cities have concentrated on urban background air quality and its effects on people outside vehicles. Background levels are usually measured on roof-tops of buildings. However, scientific evidence suggests that road users of all kinds are exposed to higher levels of air pollution than the background data might suggest. Furthermore, the evidence indicates marked differences in the exposure levels of travelers by different modes. Often counter-intuitive results have been obtained. Research done in the US and Europe is not easily adaptable to Asia, given the unique

modes of transportation in Asia, such as two-wheelers and highly used bus systems. In Asian cities the use of diesel is much higher than in the west and the implications of this for actual human exposure to air pollution is not known.

We conducted a pilot study to get preliminary estimates of personal exposures to particulate matter (PM10) and carbon monoxide (CO) while traveling on four major roads in Hanoi, Vietnam. We also investigated the effect of a few factors, such as mode of transport, route, rush-hour, and air-conditioning on the exposure levels. Investigators carried lightweight portable real-time measurement devices while traveling on buses, cars, mobikes and while walking. We compared the exposures on three 'hot-spot' roads with that on a road with less traffic. In all, 96 samples were collected over four consecutive days. We also compared CO personal exposures on one of the roads with the concentration measured by a roof-top air quality monitoring station located on that road.

The mean value of all PM10 concentrations was found to be 455 μg m^{-3} (the new World Health Organization guideline for PM10 is 50 μg m^{-3} for 24-hour means, though this is not strictly comparable, because of the longer time duration), with 580 μg m^{-3} measured on mobikes, 495 μg m^{-3} while walking, 408 μg m^{-3} in cars and 262 μg m^{-3} in buses. The mean value of all CO concentrations was 15.7 ppm, with 18.6 ppm measured on mobikes, 18.5 ppm in cars, 11.5 ppm in buses and 8.5 ppm while walking (the World Health Organization guideline for CO is 100 ppm for 15-minute means and 50 ppm for 30-minute means). Rush-hour levels for PM10 and CO were found to be higher than during non-rush hour periods. But the differences were statistically significant only for walkers (CO and PM10), car users (only for CO) and bus users (only for

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CO). In cars, switching on the air-conditioner was found to significantly reduce PM10 levels by 62%, but had no effect on CO levels. PM10 levels were lowest on the road with least traffic as compared to the three hot-spot roads. But on this road, CO levels were the second highest among the four roads considered. On one of the roads with a regular and official air quality monitoring station, the average CO level measured while traveling was 6 ppm, while that measured by the roof-top station was much lower – 1.5 ppm. The study is unique in terms of its special focus on users of two-wheelers and particulate matter. The survey has clearly provided evidence of the extremely high levels of pollution experienced by commuters, thereby justifying the need for a larger and more comprehensive assessment of human exposures and the factors that influence exposures.

Introduction

Hanoi city is the Capitol of Vietnam. Hanoi's inner population is growing rapidly, especially in the last 20 years since the "Doi Moi" (renovation) policy was implemented. Hanoi's population was 300,000 in 1954; 1,050,000 in 1990 and reached 1,800,000 in 2003.

The vehicle population is expected to continue to grow rapidly in coming years as the overall economy continues to advance. The city's vehicle fleet is projected to grow at an annual rate of 8.5% between 2000 and 2010. In 2001 there were only 100,000 four wheelers in Hanoi compared with 1.5 – 1.6 million motorcycles and a rather smaller number of bicycles. Motorcycles account for about 60% of all vehicular trips and bicycles about 30%. Without improvements in public transit, the number of motorcycles is projected to grow at an annual rate of 13% to 15% and reach 1.8 million units by 2020. Four-stroke engines with displacements less

than 125 cubic centimeters are expected to remain the dominant form of personal motorized transport. The automobile fleet is projected to grow at an annual rate of 6% between 2006 and 2010 and reach 84,000 units by 2010 (Multi-sectoral Action Plan Group, 2002). After 2010 per capita incomes in Vietnam are expected to reach the threshold at which rapid automobile-based motorization is likely to occur. The average vehicle speed in the urban area is from 18 – 32 km h^{-1}.

Traffic volumes on the city's major routes have reached 1,800 to 3,600 units per hour. Hanoi's narrow roads and numerous intersections were not designed to handle these traffic volumes. Therefore, the vehicles are obliged to idle or change frequently their speed causing chaotic traffic flow and many accidents. Motorcycles account for a much higher percentage of total vehicular flow than automobiles, and the peak transportation flow occurs in different times of the day: 7:00 to 8:00 a.m. and 4:30 to 5:30 p.m.

The Hanoi city has a well-developed street system within its central districts. Hanoi's central business area takes the form of a grid-line pattern that is surrounded by many circumferential roads with missing links. Three major arterial ring roads serve the densely settled urban area.

The average population density of Hanoi's urban area is approximately 200 persons per ha. The estimated density of persons per ha in Hang Bo quarter of Hanoi is 1,230 and 80 persons per ha in the Dien Bien quarter of Hanoi. The residents of the new housing development rely mainly on private vehicles, mostly motorbikes, as public transport serving the new housing areas is inadequate.

Hanoi's motored vehicle fleet includes a high percentage of old cars and trucks emitting harmful air pollutants. In the transportation sector, gasoline-burning cars, trucks and motorcycles are major sources of carbon monoxide (CO) and hydrocarbons (HCs). Diesel buses and trucks are the main sources of sulfur dioxide (SO2) and nitrogen oxides (NOx). Both diesel and gasoline vehicles emit suspended particulate matter (SPM) and PM10.

The roads and streets surfaces contribute to high ambient dust concentrations, often above the allowable limit due to them being repaired, rehabilitated and newly constructed. At the traffic intersections, concentrations of air pollutants exceed Vietnam's standards of ambient air quality. In August 2000, hourly concentrations for three periods (morning, noon and afternoon) were reported for five traffic intersections, namely, Nga Tu So, Cau Giay, Nga Tu Vong, Chuong Duong Bridge as well as the ancient city area. The data indicated that hourly levels of SPM ranged from $0.4 - 1.5$ mg m^{-3} exceeding the Vietnamese standard of 0.3 mg m^{-3}. The hourly average CO level ranged from 2.0 to 6.5 mg m^{-3}, which fell within the hourly ambient standard of 40 mg m^{-3}. However, these CO levels are expected to go higher due to growth in the motor vehicle population. (Multi-sectoral Action Plan Group, 2002)

Air pollution is concentrated along traffic thoroughfares where people live and work. Fine particles are responsible for cases of respiratory disease and premature death every year. Most particle pollution originates from combustion operations and from vehicles. These particles are so small that they can bypass respiratory defenses and lodge deep in the lungs, worsening lung diseases such as asthma, and increasing the risk of heart attack and premature death. Air

pollution from emissions interferes with the development and function of the central nervous system, as well as the cardiovascular and reproductive systems. The least mobile populations – the poor, the young and the elderly suffer particularly.

Roadside Monitoring Survey

To address the need for better information on roadside air quality the Center for Environmental Engineering of Towns and Industrial Areas (CEETIA), Hanoi, measured roadside air pollutant concentrations on Giai Phong road, a major traffic artery in Hanoi, using a mobile monitoring station located about 200 meters from the Giap Bat Railway Station. One purpose of the study was to determine whether roadside concentrations were significantly different than air quality measurements made by CEETIA's fixed-site monitor located about one kilometer from the mobile monitoring station and 15 meters above ground on the university campus. Fixed-site monitors are typically used to determine compliance with ambient air quality standards. The US Environmental Protection Agency (EPA) provided training to CEETIA's staff on monitor use, quality assurance, and data analysis. CEETIA collected ambient air quality data at the mobile station during two-week periods in both November 2004 and June 2005. The study found that daily average concentrations of several air pollutants (PM10, SO2, NO2, CO and O3) were higher at the mobile monitoring station than at CEETIA's fixed-site monitor (Pham Ngoc Dang *et al*., 2005).

The findings of CEETIA's roadside monitoring surveys are consistent with theory and expectations. Urban settings place people in close proximity to air pollutants from mobile sources. The proximity of buildings next to roads reduces opportunities for atmospheric dilution

of these air pollutants. Moreover, higher concentrations of air pollutants may occur in street canyons compared to roadways in open areas. Using emission and dispersion models to profile human exposures in these settings is very complex. Instead of models, most assessments of exposure in these settings rely on measurements in the field. The simplest approach uses data from a set of fixed-site monitors as surrogates of population exposure on the assumption that there is very little spatial variation in air pollutant concentrations. That approach is more accurate for some pollutants (e.g., PM10) but not for others (e.g., CO), and is more accurate for stationary people (e.g., some children and elderly) but not for workers who may spend nearly three hours per day commuting. Roadside monitoring stations, such as the one deployed by CEETIA in Hanoi (discussed above), may reveal hot-spot locations, i.e., locations whose concentrations exceed the average for the entire urban area. (Colvile *et al*., 2002)

Studies of human exposure are needed to quantify the impact of air pollution on public health. However, quantifying that impact in urban areas is difficult and challenging, because large numbers of people may be exposed to relatively low levels over long periods of time. Such exposures result in rare health problems that are difficult to value or even attribute to air pollution. On the other hand, a substantial number of people can be exposed to relatively high levels of air pollution for short periods of time due to the nature of their daily activities or occupations. Hence, it becomes important to measure air pollutant exposures as people perform their daily activities.

The aim of our study was to get an estimate of the range of concentration of major pollutants (PM10 and CO) under different circumstances and to investigate the impact of a few factors on

concentration levels. A survey of the literature on commuters' exposure to air pollution in developed countries points to knowledge gaps related to aspects that are unique to Asia, such as high use of 2-wheelers and very heterogenous composition of traffic on most types of roads. Therefore, our study has an emphasis on users of 2-wheelers.

Methods

We conducted the pilot survey (in October 2006) on three arterial roads that had been earlier identified as some of the major 'hot-spots' of Hanoi – Truong Chinh, Giai Phong and Pham Van Dong (TDSI 2005). Giai Phong and Pham Van Dong roads are very broad and in sections have wide medians as well. In contrast, though Truong Chinh has high traffic volumes, in many sections it is narrow with multi-story buildings very close to the road. We compared the conditions on these roads with those on a distributor road (chosen arbitrarily), which was supposed to have much less traffic – Tran Hung Dao. On two of these roads are located official air quality monitoring stations of the Hanoi network. These are CEETIA's station on Giai Phong road and the Hanoi Center for Environmental and Natural Resources Monitoring and Analysis (CENMA) station on Pham Van Dong road. Four modes of transportation were considered – buses, cars, mobikes, and walking. Most buses plying on the major routes are modern, air-conditioned and run on diesel. We used CEETIA's official car, with an air-conditioner, on all days of the study. Mobikes personally owned by some of the investigators were used in the study.

Prior to the first day of monitoring, we had identified on each road two pairs of bus-stops. The distance between the bus stops, on one side of the road, was approximately 4 – 5 km. We

identified the corresponding bus stops on the other side of the road as well. A previous survey had shown that average trip distances traveled by bus users and motorcyclists were 6.5 km and 5.2 km respectively (TDSI 2005). The routes chosen were mostly straight without sharp turns. That is, the investigators remained on a single road throughout the monitoring. The monitoring scheme was as follows. First, during the rush-hour period, two investigators boarded a bus at the pre-identified starting point and switched on the samplers. At the same time two investigators traveled alongside the bus in the car (with the air-conditioner on). The investigators in the bus got off the bus at the end point, switched off the monitors and crossed over to the other side of the road and waited for the bus traveling in that direction. The investigators in the car too, switched off the monitors and turned the car around. The monitoring was then repeated in that direction when a bus came along. Immediately after this, the investigators who were earlier on the bus, got on to mobikes and switched on the monitors, riding between the two bus stops. The investigators in the car followed them, monitoring as earlier, but this time with the air-conditioner switched off. The two groups then conducted a monitoring run on the other side of the road as well. Finally, the investigators in the car left the car and conducted monitoring while walking between the bus stops. The investigators on the mobikes also did a new monitoring run in both directions. Thus, we have twice the number of samples for mobikes and cars as compared to buses and pedestrians. Currently, mobikes have 71% of the modal share of transport. Though the share of cars is just 3%, the automobile population is growing rapidly at 10% per year. Based on these facts we felt that having larger samples for mobikes and cars was justifiable.

This pattern of monitoring was then repeated on the same road during the non-rush hour period. Similar twice-a-day monitoring was conducted on the other roads on consecutive days. Earlier

surveys had established that rush-hour traffic occurs between 7 – 8 am and from 4 – 5 pm (Multi-sectoral Action Group 2002). Accordingly, in our monitoring scheme, the first session was between 7 – 9 am and the second session was conducted between 10 am – 12 pm. The total sample size was therefore 96 for the main part of the study.

On two days, we also monitored PM10 and CO levels in road-side cafes (which are very common in Hanoi) in between the in-vehicle monitoring sessions. These cafes were located on Giai Phong and Pham Van Dong roads.

Investigators (mainly faculty and students) carried personal lightweight monitors while traveling (Figures 1 and 2). For CO measurements we used a portable electrochemical monitor, the Model T15n instrument from Langan Products, Inc. This instrument has many features that make it ideal for field surveys. The monitor measures and records CO concentrations to the nearest 0.055 ppm, over a range of 1 to 200 ppm. Besides CO, the instrument can also measure temperature. It has a storage capacity of 43,000 CO samples and a minimum sampling frequency of 1 second. Stored data in the monitor can be downloaded to a personal computer for statistical analysis. Batteries supply operating power for several months of continuous use. The Langan monitor has been used in studies by Jantunen *et al*. (1998) and Flachsbart *et al*. (2004). The instruments were calibrated in Honolulu, USA at the East-West Center in late September 2006 by zeroing them under clean conditions and using a span gas of 60 ppm (manufactured by Calgaz LLC, Cambridge, USA). In Hanoi, the instruments were zeroed every morning in a clean environment using an air tight tedlar bag fitted with a HEPA filter.

To measure PM10 we used a nephelometer, which measures the intensity of light scattered by airborne particles passing through their sensing chamber, manufactured by Thermo Inc., model PDR -1000. The intensity of the light is linearly proportional to the concentration of the particles in the chamber. This passive monitor measures mass concentrations of dust, smoke, mists and fumes, ranging in size from 0.1 – 10 µm. The instrument estimates mass concentrations ranging from 0.001 to 400 mg m^{-3}. This instrument's performance has been widely studied under different operating conditions (Wu, Delfino, Floro *et al*. 2005, Chakrabarti, Fine, Delfino, *et al*. 2004, Muraleedharan and Radojevic 2000). The monitors were less than a year old and had been factory-calibrated. In Hanoi, the instruments were zeroed every morning in a clean environment using an air tight tedlar bag fitted with a HEPA filter.

We compared the nephelometers with a portable gravimetric sampler at the Hanoi Center for Environmental and Natural Resources Monitoring and Analysis station on Pham Van Dong road. An Airmetrics MiniVol model sampler with an impactor based size selection device was used. All monitors were placed in close proximity and operated for 5 hours. The PM10 result from the Airmetric sampler was 250 µg m^{-3}. The data from the two nephelometers were 206 and 220 µg m^{-3}. We have not corrected our readings to correspond to the results from the gravimetric sampler mainly because it rained during the sampling, so the monitors had to be moved about temporarily. The impact of this on all the readings is uncertain.

Data quality control and assurance procedures included studying the correlations among similar monitors by collocating them during special sampling sessions. We observed that the correlation

coefficient, r, ranged from 0.841 to 0.988 for the PM10 monitors and from 0.997 to 0.999 for the CO monitors.

In addition to PM10 and CO we also measured temperature and relative humidity using the HOBO U10 data logger (made by Onset Computer Corporation). Extreme weather conditions are known to affect the performance of both types of instruments. Outliers in the data, if any, could potentially be due to extreme weather conditions.

The sampling frequency for all the instruments described above was set to 12 seconds. The CO and HOBO monitors were set to begin logging continuously from early morning and at the end of the day the data were downloaded as a single file for each of these instruments. The data logger was then cleared. On the other hand, PM10 monitors were switched on for every sample and switched off at the end of the sample run. Thus, each sample was stored in a different file identified by a unique tag by the monitors' internal software. Investigators manually recorded the tag number for each sample on a data sheet. The PM10 monitors had sufficient memory to accommodate all the data. So there was no need to erase the internal memory every day. All the monitors' internal clocks had been synchronized with a single laptop's clock, on which the downloading softwares had been installed. The PM10 monitor's data file indicated the true start and end times for a single sample. The corresponding sections from the downloaded CO and HOBO files were copied and pasted into a single Excel worksheet that had been exported from the PM10 data logger. We did the statistical analysis using SPSS (version 12).

Results and discussion

The mean value of PM10 concentration was found to be 455 µg m^{-3} (the new World Health Organization guideline for PM10 is 50 µg m^{-3} for 24-hour means), with 580 µg m^{-3} measured on mobikes, 495 µg m^{-3} while walking, 408 µg m^{-3} in cars and 262 µg m^{-3} in buses. The mean value of CO was 15.7 ppm, with 18.6 ppm measured in mobikes, 18.5 ppm in cars, 11.5 ppm in buses and 8.5 ppm while walking (Table 1) (the World Health Organization guideline for CO is 10 ppm for 8-hour means and 50 ppm for 30 minute means). The variability of levels for CO was much higher than for PM10, judging by the coefficient of variation and geometric standard deviation indicators.

Though particulate matter is increasingly being considered as the most important air pollutant of concern in Asia, there are not many studies that have looked at the exposures of 2-wheeler users to particulate matter. A study in New Delhi, India showed much higher levels of PM5 for car users (2860 µg m^{-3}) as compared to our study (Saksena *et al*. 2006). It is known that at the time when this study was conducted in Delhi, the ambient air pollution was much worse than in Hanoi. Even for bus users the Delhi study observed higher PM5 levels (800 µg m^{-3}). However, for car users the results were similar (370 µg m^{-3}). But it is also possible that the differences in results could be partly due to the differences in sampling methods. The Delhi study used the more traditional and accurate gravimetric method, while in our study we used nephelometers. Other studies in developing countries have reported the following range of PM10 values – Cars: 65 – 140 µg m^{-3}; Bus: 125-184 µg m^{-3}; and subway: 55-78 µg m^{-3} (Chan, Lau, Lee, *et al*. 2002; Chan, Lau, Zou, *et al*. 2002; Zhao, Wang, He, *et al*. 2004; Chau, Tu, Chan, *et al*. 2002).

Figures 3 and 4 indicate the variation in data across the four modes of transport through box-plots. For both pollutants cars showed the highest variability. This could be because in this survey, cars were operated in two modes – with and without air-conditioning. Many studies conducted in USA and Europe that primarily measured gaseous pollutants indicated that car users experience higher concentrations than pedestrians. In our survey we observed the same pattern for CO but not for PM10. The reason for this could be that in the spatial scale of interest here, vehicles are the only source of CO, whereas PM10 could have other sources, such as re-suspended dust near the curb. Zhao, Wang, He *et al*. (2004) also observed that pedestrian exposure to PM10 was higher than public transportation modes in Guangzhou, China (but the converse was true for CO).

As Figure 5 shows, PM10 levels were lowest on the road with least traffic (Tran Hung Dao) as compared to the three hot-spot roads. But on this road, CO levels were the second highest among the four roads considered (Figure 6). Though Tran Hung Dao road has comparatively lower traffic flows, it is much narrower than the other roads and has multi-story buildings very near the curb. We speculate that such a geometry may not be allowing CO to disperse rapidly, thus leading to a build-up of concentration. The road also has many trees, which, we speculate, in the case of PM10 may be suppressing PM10 levels. The effect of trees on gaseous pollutants such as CO is less pronounced.

Rush-hour levels for PM10 and CO were found to be higher than during non-rush hour periods (Figures 7 and 8). But the differences were statistically significant (Table 2) only for walkers (CO and PM10), car users (only for CO) and bus users (only for CO). Judging by the exposures

of walkers it may be said that the general ambient air pollution levels are higher during rush-hour traffic, but for those right on the road, the patterns are more complicated and call for further investigation.

 In cars, switching on the air-conditioner was found to significantly reduce PM10 levels, but had no effect on CO levels. In cars, mean PM10 levels with the air-conditioner on were 595 µg m^{-3} Without the air-conditioning and with all windows rolled down the mean PM10 levels were 222 µg m^{-3} (t-test results: t = 7.13, p <0.001). This corresponds to a removal efficiency of 62%. A t-test indicated that the levels of PM10 in the air-conditioned car were very similar to those in the air-conditioned buses (262 µg m^{-3}). The differential effect of air-conditioning on PM10 and CO is understandable because the filters in cars are designed only to remove larger particles and not gases from the cabin air-stream. Other studies in Asian cities have also observed the same effect of air-conditioning on PM10 levels (Zhao, Wang, He *et al*. 2004, Chan, Lau, Lee *et al*. 2002)

Correlations between PM10 and CO were generally very weak (Table 3). In unshielded modes of transport, such as mobikes, and walking, the correlations were slightly higher. We are unable to explain the negative correlation observed in buses. These results imply that though CO is easier to measure, it cannot be used as a reliable surrogate indicator for PM10 under such conditions.

One of the roads (Pham Van Dong road) has a regular official air quality monitoring station operated by CENMA. Though at this station normally all major pollutants are monitored, during this period their PM10 monitor was under repair. On this road the average CO level measured while traveling was 6 ppm, while that measured by the roof-top station was much lower – 1.5

ppm (as measured by their NDIR instrument). Traditional ambient air quality monitoring networks provide very useful assessments of broad trends and patterns, and in some cases may provide fairly reliable estimates of relative risks to human health. But as this study seems to indicate, data from ambient air quality monitoring stations can grossly underestimate absolute risks to air pollution.

Table 4 shows pollutant levels measured in two roadside cafes. Monitoring was done in the cafes for approximately half an hour on two consecutive days. The PM10 levels are unexpectedly high – higher than concentrations measured in most modes of transport. In one of the cafes CO levels were also very high, comparable to what we measured in buses.

Conclusions

The survey has clearly provided evidence of the extremely high levels of pollution experienced by commuters, thereby justifying the need for a larger and more comprehensive assessment of the exposures and the factors that influence exposures. The survey also highlights the need to consider comprehensive assessments of exposures within buildings, such as cafes, shops, offices and homes which are very near the road. Future studies that build on this one need to focus on the following issues:

- Measure exposures of actual commuters, including cyclists. The actual exposures measured should also consider the time spent traveling.
- Study seasonal patterns in exposure to air pollution.

- Develop a more elaborate definition of road types, based on factors such as traffic flow, traffic composition, sources of pollution, types of buildings along the road, etc.

- Examine in greater detail the intra-day temporal patterns, including assessing the situation during the afternoon rush-hour period.

- Develop stringent and comprehensive protocols for data downloading and management because real-time devices, such as the ones used in this study tend to generate huge databases. With many investigators and institutions involved that need to share the data, this becomes even more vital.

- All of the above have to be preceded by improving project-specific methods to measure particulate matter. There are far less uncertainties associated with CO instrumentation.

The policy relevant aspects of a full-scale study based on this pilot are:

- Local authorities could use the data to encourage commuters who travel on motorcycles to switch to using buses to reduce their personal exposures. Such 'individualized' information has greater potential to modify commuters' behavior as compared to general area-wide information (e.g.: ambient air levels). This information my be especially more motivating for already vulnerable population sub-groups.

- Exposure estimates may indicate that the benefits of intervention projects may have been underestimated in absolute terms.

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Table 1: Descriptive statistics of PM10 and CO concentration across modes of transport

	PM10 (µg m^{-3})					CO (ppm)				
	Bus	Car	Mobike	Walking	All	Bus	Car	Mobike	Walking	All
N	16	32	32	16	96	16	32	32	16	96
Mean	262	408	580	495	455	11.5	18.5	18.6	8.5	15.7
CV (%)	45	59	34	38	50	72	66	47	83	66
GM	242	343	547	460	397	9.2	15.7	16.3	5.1	1.88
GSD	1.46	2.07	1.38	1.32	1.56	2.61	1.65	1.46	2.65	1.88

CV = coefficient of variation, GM = geometric mean, GSD = geometric standard deviation

Table 2: t-test results for testing the difference in concentration between rush hour and non-rush sessions

Mode	Pollutant	t	Df	Sig. (2-tailed)	Mean Difference
Bus	PM10	.929	14	.369	.05464686
	CO	2.355	14	.034	8.554952
Car	PM10	1.532	30	.136	.12665699
	CO	2.098	30	.044	8.541732
Mobike	PM10	1.050	30	.302	.07370385
	CO	.907	30	.372	2.787932
Walking	PM10	3.193	14	.007	.23330476
	CO	1.859	14	.084	6.075624

Table 3: Correlation between PM10 and CO concentrations across modes of transport

Mode	Pearson correlation, r
Bus	-0.238
Car	0.252
Mobike	0.455[*]
Walking	0.817[*]
All	0.335[*]

[*] Correlation is significant at the 0.01 level (2-tailed)

Table 4: PM10 and CO levels in roadside cafes

Statistic	PM10 (µg m-3)		CO (ppm)	
	Giai Phong road	Pham Van Dong road	Giai Phong road	Pham Van Dong road
n	148	127	148	127
Mean	404	617	3.2	11.3
Coefficient of variation (%)	18	32	75	8
Geometric mean	400	591	2.8	11.3
Geometric standard deviation	1.14	1.53	1.5	1.09

N refers to the number of 12-second intervals logged during sampling

Figure 1: Monitoring in a bus

Figure 2: Monitoring on a mobike
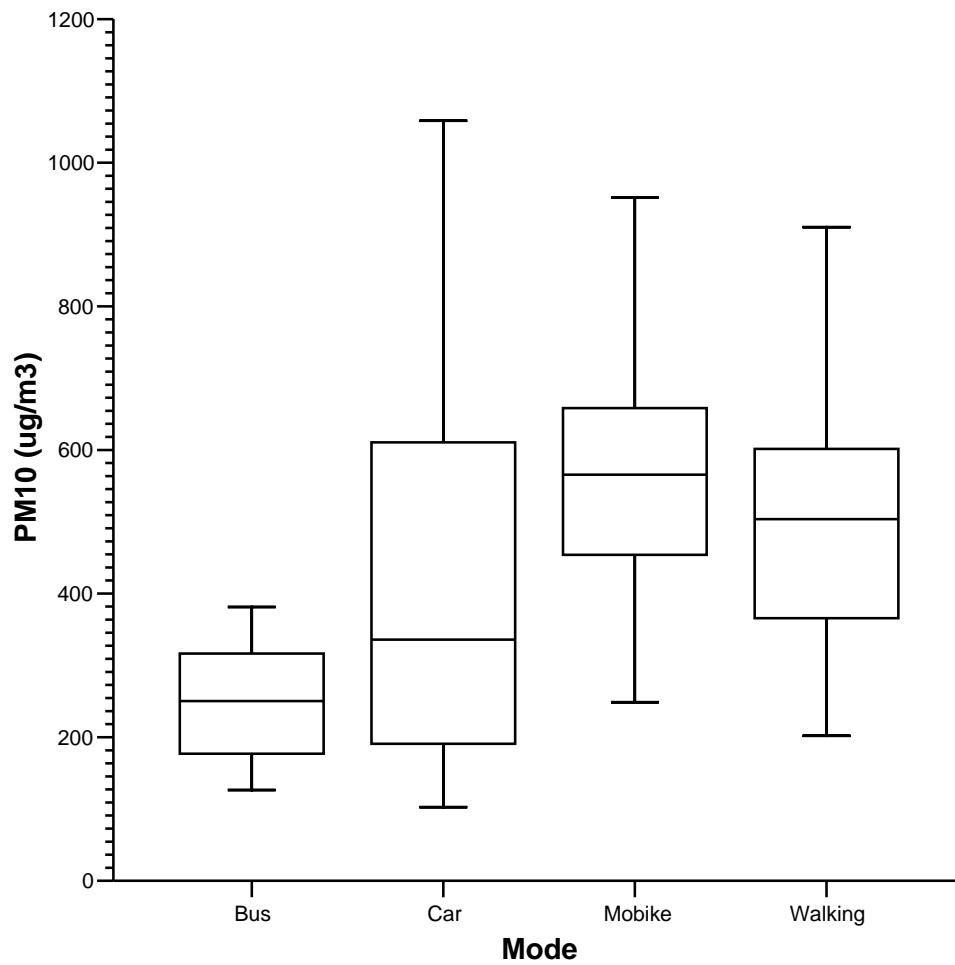
Figure 3: Box plot of PM10 concentration across modes of transport
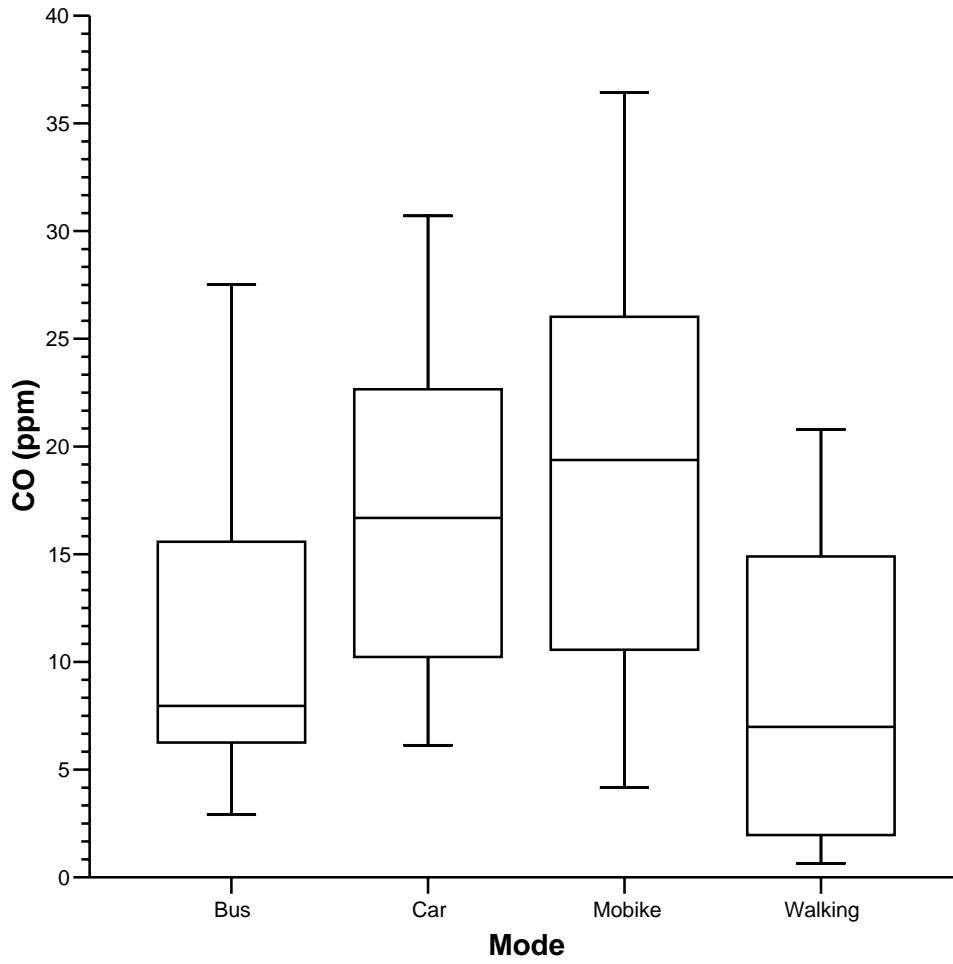
Figure 4: Box plot of CO concentration across modes of transport
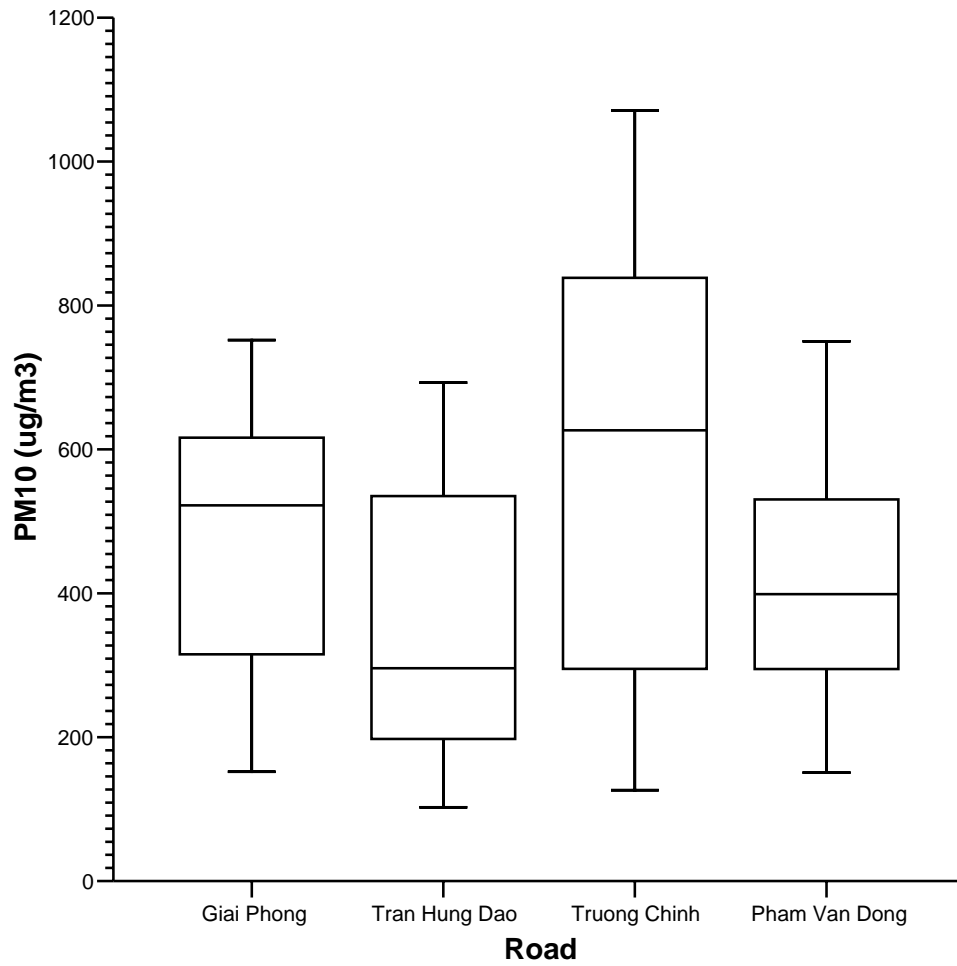
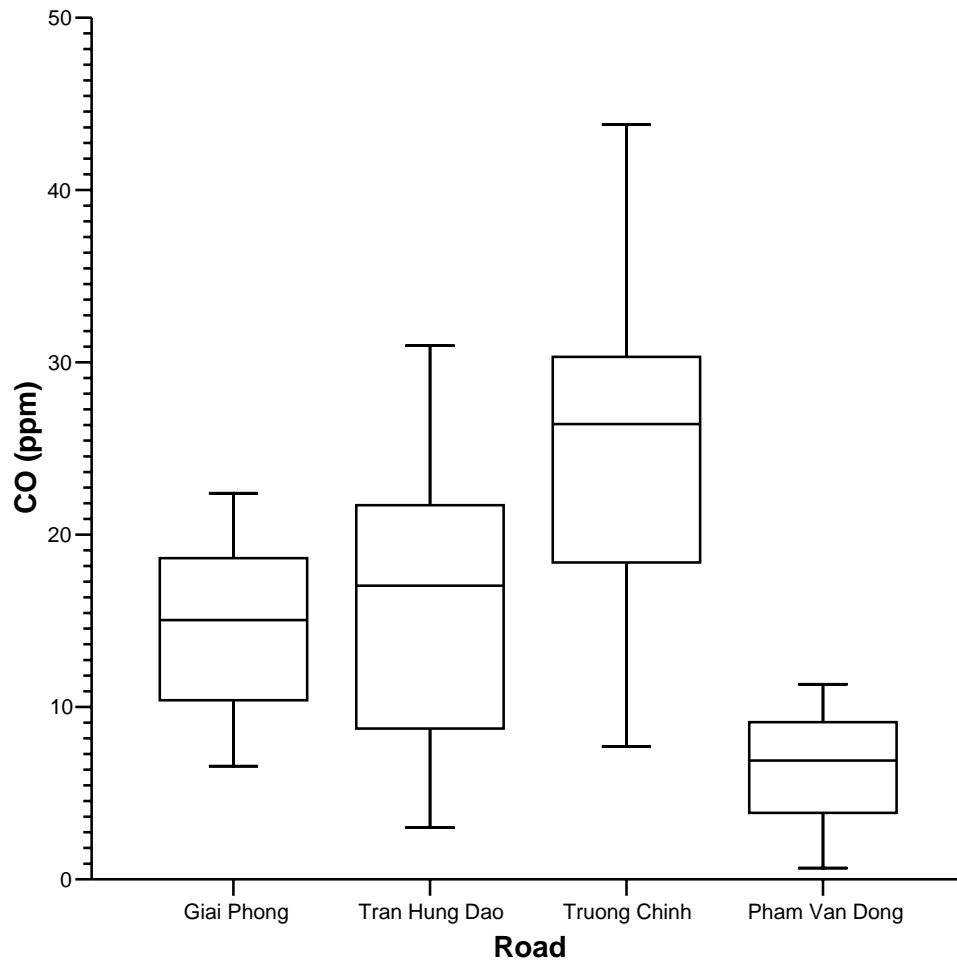**Figure 5: Box plot of PM10 concentration across roads**

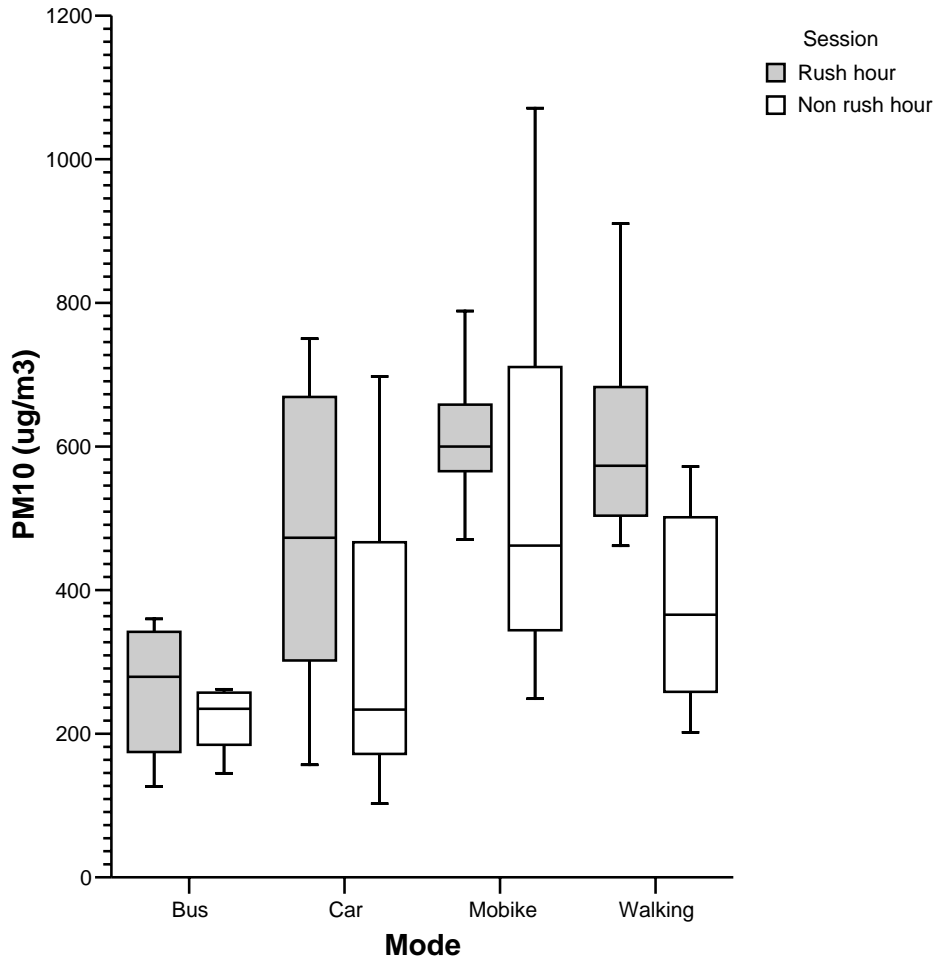**Figure 6: Box plot of CO concentration across roads**
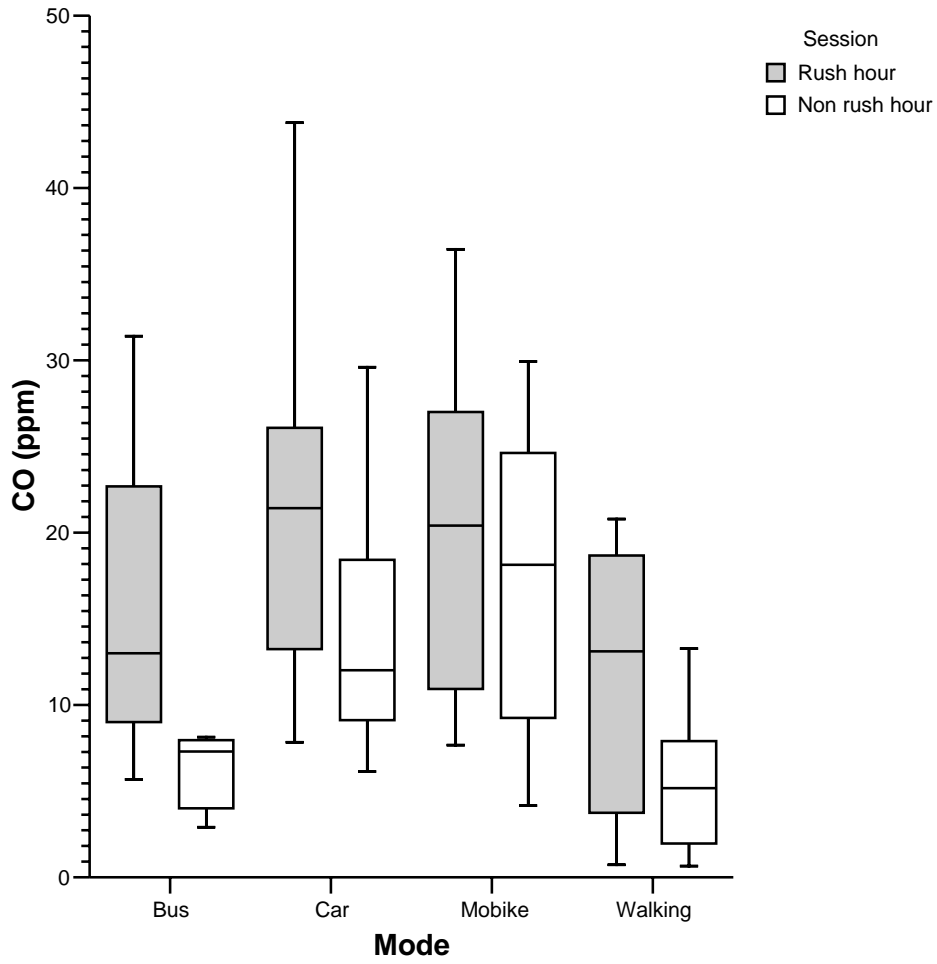
Figure 7: Effect of rush-hour on PM10 concentration

Figure 8: Effect of rush-hour on CO concentration