Aerosol and Air Quality Research **11** (2011) pp.689-695.

Exposure to PM_{10}, $PM_{2.5}$, PM_1 and Carbon Monoxide on Roads in Lahore, Pakistan

Ian Colbeck[1*], Zaheer Ahmad Nasir[1], Shakil Ahmad[1,2] and Zulfiqar Ali[3]

[1]*Department of Biological Sciences, University of Essex, Colchester, CO4 3SQ, U K*
[2]*Institute of Plant Pathology, University of the Punjab, Lahore, Pakistan*
[3]*Department of Wildlife and Ecology, University of Veterinary and Animal Sciences Lahore.*

Abstract

Particulate matter pollution is one the major environmental concerns in Pakistan. Over the past 20 years there has been a considerable increase in the number of motor vehicles. The present study was conducted to assess journey time and roadside exposure to particulate matter and carbon monoxide along major roads of Lahore during November, 2007. Measurements of particulate mass and carbon monoxide were carried out continuously inside an air conditioned vehicle, while commuting, and outside the vehicle at 36 different locations in the city. Additionally, monitoring was undertaken at a background site throughout the period. The overall mean journey-time concentrations of PM_{10}, $PM_{2.5}$, PM_1, $PM_{10-2.5}$ and CO were 103 $\mu g/m^3$, 50 $\mu g/m^3$, 38 $\mu g/m^3$, 53 $\mu g/m^3$ and 8 ppm, respectively. At the roadside average PM_{10}, $PM_{2.5}$, PM_1, $PM_{10-2.5}$ and CO concentrations were 489 $\mu g/m^3$, 91 $\mu g/m^3$, 52 $\mu g/m^3$, 397 $\mu g/m^3$ and 4 ppm, respectively. The highest levels were found at the sites with traffic congestion reflecting, not only, the large contribution of automobile exhaust but also the resuspension of road dust. The majority of public transport vehicles in Lahore are not air-conditioned and it is very likely that commuters are exposed to the similar high levels of pollution.

Keywords: Pakistan, particulate matter, carbon monoxide, exposure, air pollution

*Corresponding author: E-mail: *colbi@essex.ac.uk*, Tel +44-1206-872203, Fax: +44-1206-872592

Introduction

In recent years many Asian countries have experienced significant economic growth leading to increased urbanization, motorization and energy use. As a result poor air quality has emerged as a major environmental concern due to lack effective control measures. Worldwide urban air pollution is estimated to be responsible for 865,000 premature deaths every year and about 60% of these deaths occur in Asia (World Health Organisation, 2007). The Clean Air Initiative for Asian Cities (CAI-Asia, 2008a) has reported that, in 64 cities, ambient Total Suspended Particulate (TSP) and PM_{10} remain above the WHO guidelines. Similarly, a study on urban air quality in Asia by Hopke *et al*., (2008) concluded that levels of particulate pollution, in many cities, were higher than standards in developed countries. Vehicular emissions are the principle source of fine particulate matter pollution in urban areas as a result of an unprecedented growth in passenger vehicles in the region. Two-stroke engine vehicles are ubiquitous in South Asian cities, where they constitute approximately half of the total vehicle numbers and contribute significantly to urban air pollution (Kojima *et al*., 2000). It is known that two stroke engines have high emission rates for hydrocarbons and particulate matter than four stroke engines due to poor fuel utilization.

Among the south Asian countries Pakistan, is the world's sixth most populous country with an estimated population of 169.9 million (Pakistan Economic Survey, 2009-10). Like many other countries in the region, Pakistan is facing environmental degradation. Among various environmental issues, air pollution is of greatest concern. Vehicular emissions are the main driver of air pollution in urban regions. A dramatic increase in number of vehicles on the road has resulted into severe air pollution problems. In 2005 the total numbers of registered vehicles in the country were more than 5 million and with the highest share attributable to two wheelers (CAI – Asia 2008b). By 2009–10, the numbers of two wheelers and rickshaws had increased by 146 and 34.4% over the previous 10 years (Pakistan Economic Survey, 2009-10). The use of unclean/adulterated fuels, ageing vehicles, inefficient automotive technology and lack of emission control strategies has lead to soaring levels of air pollution in urban centers of the country. According to Gujar *et al*., (2008) Karachi was the most polluted city in the world with respect to TSP.

A great number of studies have reported the association of particulate matter (PM) with chronic and acute cardiopulmonary problems (Zanobetti and Schwartz, 2009; Franklin *et al*. 2007; Pope and Dockery, 2006). The Pakistan Strategic Country Environmental Assessment World Bank Report (World Bank, 2006) reported that the annual health burden due to particulate matter was 1% of gross domestic product and was responsible for 22,000 premature deaths among adults and 700 deaths among children under 5 years. In another study, on health risks in megacities of the world due to air pollution Gurjar *et al.* (2010) reported that, among the mega cities of the world, Karachi had highest number of excess deaths (approximately 15,000/year) due to air pollution.

This clearly highlights the alarming levels of air pollution in Pakistan, where air quality management capabilities are still minimal. This state is further compounded by the rapid shift of population from rural areas to town centres. Approximately 35% of the population resides in towns and cities and it has been estimated that this number will grow up to 60% by 2050 (United Nations Population Division, 2009). Recently ambient air quality standards have been announced and it was not until March 2007, that continuous monitoring stations were established in 5 major cities of Pakistan: Karachi, Lahore, Quetta, Peshawar and Islamabad. Colbeck *et al.* (2010) reviewed the state of ambient air quality in Pakistan and concluded that the available information on air quality in Pakistan is sparse and sporadic but clearly reflects the severity of the problem. Air quality is deteriorating with enormous speed and has been recognized as a serious problem by the Government and various other organizations. However, little work has been done in this regard. Those studies which have been carried out reveal that the current levels of PM, SO_2, NO_2, CO, and Pb are many times higher than WHO air quality guidelines.

Over the last few decades there have been significant improvements in various transport modes which have resulted in increased mobility and today a large proportion of the working population spend a considerable time commuting. Knowledge of particulate matter concentrations on or near roads is essential to calculate, not only the total human exposure but also to identify the potential sources and design effective control measures. The information regarding the exposure of the commuter to particulate air pollution is potentially important but studies of journey time exposure to particulate matter are relatively rare. Most of these studies have focused on exposure to PM in motorized transport or to cyclists and were conducted in the developed world: UK (Bevan *et al*., 1991; Adams *et al*., 2001; Gee and Raper, 1999; Briggs *et al*., 2006; Briggs *et al*., 2008; Gulliver and Briggs, 2007; Nasir and Colbeck, 2009); Germany (Pramal and Schierl, 2000); China (Chan et al., 2002a); Hong Kong (Chan et al., 2002b; Kaminsky et al., 2009), Italy (Geiss *et al.*, 2010).

Few data are available on journey time and stationary roadside exposure to particulate matter on roads in South Asian countries. Akbar and Ashmore (1997) reported in-vehicle levels for Delhi and Mukherjee *et al.* (2003) for Calcutta. Saksena *et al*. (2007) carried out an investigation on daily exposure to Respirable Suspended Particulate (RSP – below 5μm) and CO in vehicle micro-environments in Delhi. They reported that mean RSP and CO during travelling in different modes of transport ranged from 370 (car) to 2,860 $\mu g/m^3$ (two wheeler) and 8 to 19 ppm, respectively.

Hence, the present study was conducted to assess journey time and roadside exposure to particulate matter (PM_{10}, $PM_{2.5}$, PM_1) and carbon monoxide (CO) along major roads of Lahore, Pakistan during November 2007. The size fractionated data for particulate matter mass helps to understand the contribution from automobile exhaust; fine particles ($PM_{2.5}$) are derived primarily from direct emissions from combustion processes.

Materials and Methods

Site

Lahore is the provincial capital of Punjab province and is the second most populous city of Pakistan. It lies between 31°15′ and 31°45′ north and 74°01′ and 74°39′ east with a total area of 1772 km^2. According to the Government of the Punjab the estimated population of Lahore, in 2001, was 7 millions (Government of Punjab, 2010). However, since then it is very likely that this number has grown. The proposal for Lahore rapid mass transit system project reported that estimated population in 2006 was 8.7 millions. (Asian Development Bank, 2008) Within Pakistan's administrative structure Lahore is divided into nine towns. The weather of Lahore is hot during the months of May, June, and July, when the temperatures can exceed to 45°C. The monsoon starts in August with heavy rainfall. The coldest months are December, January and February where the temperature can fell to below 0°C (Government of Punjab, 2010).

Sampling design

Two circular routes were designed within all the nine towns, covering all the important roads in the city (Figure 1). Route I encompassed the centre of the city, with heavy traffic loads all day. The major part of route II was in well developed and greener parts of the city, with low traffic load, and better road networks. Real time measurements were carried out continuously for half an hour inside an air conditioned vehicle, while commuting, and between 20 – 30 minutes outside the vehicle. A total of 36 roadside measurements were made on both the routes with 17 on route I and 19 on route II. Additionally, continuous monitoring was carried out at a background site throughout the measurement period. This background site was in the grounds of the Department of Mycology and Plant Pathology, University of Punjab Lahore and approximately 600 meters away from main roads. Sampling was conducted between 09.00 – 20.00 hrs. All the samples were taken at respiratory levels and the sampling location was carefully selected to be free of any obstructions. In the vehicle, the analysers were placed on the front seat next to the driver at a desirable height. The roadside measurements were made on the pavements at the height of 1m. The sampling was continuous and at an interval rate of 1 minute for both in-vehicle and roadside. Three repeated measurements were taken on three different days of the month on both routes. The weather was dry during the days of measurement and the outdoor temperature and relative humidity were in the range of 20-31°C and 20-50%, respectively.

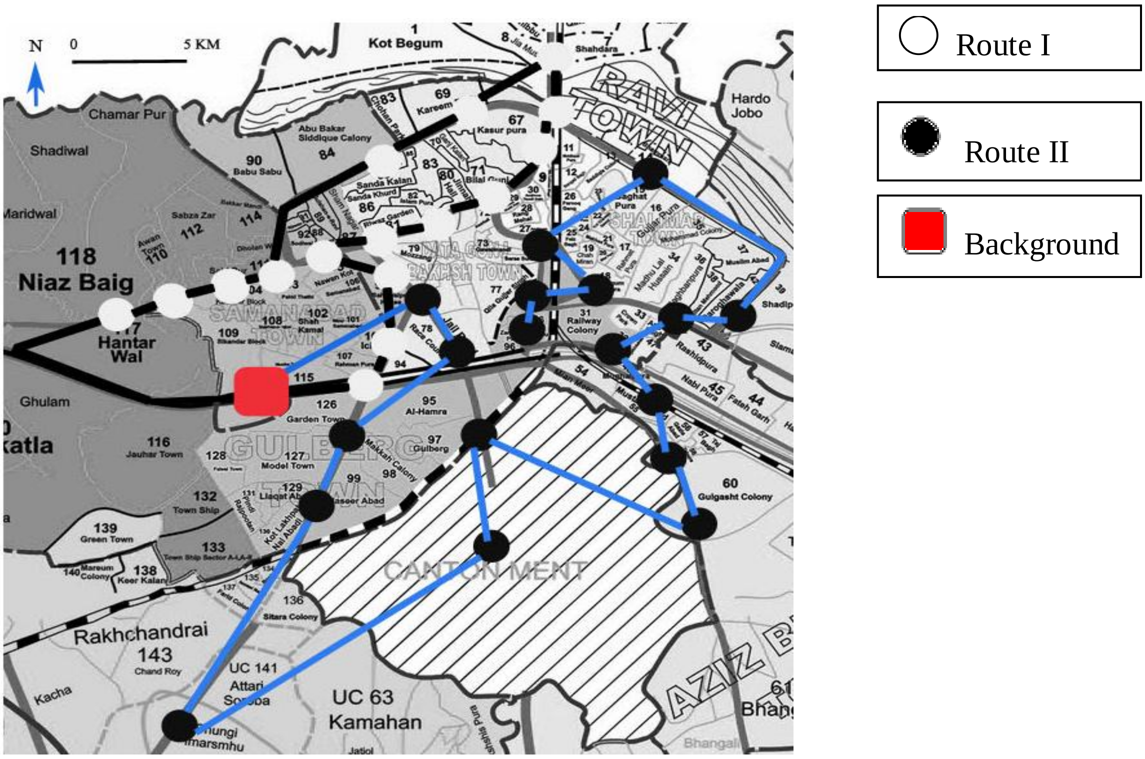

Figure1. Map of Lahore showing the roadside and background sampling locations for routes I and II.(http://pportal.punjab.gov.pk/portal/portal/mediatype/html/group/300/page/default.psml/js_pane/P-11b5304069d-10014?nav=left)

Instrumentation

The mass concentration of particles was monitored using two GRIMM Aerosol Spectrometers (Model 1.101 and 1.108, Grimm Aerosol Technik GmbH, Ainring, Germany). Temperature, relative humidity and carbon monoxide was recorded with two *Gasprobe IAQ* 4 (BW Technologies Ltd, Canada) at an interval of one minute. One *Gasprobe IAQ* 4 was used on road measurements (journey time/roadside) while the other situated at the background site.

Intercomparison and determination of the calibration factor

Both monitors were operated side by side for 12 hours and intercomparision between them showed a variation of ±10 %. The model 1.108 was used for the vehicle/roadside measurements and the 1.101 was used at the background site. Before the sampling campaign, both of these aerosol spectrometers were factory calibrated. A gravimetric correlation was carried out with Stearin and an optical calibration cross reference was performed with spherical glass beads with a density of 2.8 g/cm^3 and a refractive index of 1.36. However a calibration factor was also determined. GRIMM Aerosol Spectrometers collect particles on an integrated 47mm PTFE-filter inside the spectrometer. The spectrometers also keep a record of the air volume sampled and total mass collected. In order to calculate the calibration factor (C factor), pre-weighed filters were placed inside the monitors and after each measurement campaign the filters were re-weighed. The calibration factor for the vehicle/roadside measurements was 0.80. The data collected by the instruments was corrected according to this factor. All the filters were equilibrated before initial and final weighing for a minimum of 24 hours in controlled chamber. The filters were weighed thrice before and after the sampling by using a microbalance.

Data Analysis

Mean values, along with standard deviations, were calculated for each roadside measurement and journey time for both routes and at the background site. Due to differences in the routes the data were analysed separately.

Result and Discussion

The ambient temperature and relative humidity during the sampling period was in the range of 21 to 30°C and 30 to 65%, respectively. Table 1 summarizes the concentrations of particulate matter and CO in vehicles, roadsides and at the background site within Lahore. The mean journey-time concentrations of PM_{10}, $PM_{2.5}$, PM_1, $PM_{10-2.5}$ and CO for route I were 74 $\mu g/m^3$, 36 $\mu g/m^3$, 27 $\mu g/m^3$, 38 $\mu g/m^3$ and 9 ppm, respectively. For comparison the mean concentrations at the roadside on the same route were 583 $\mu g/m^3$, 90 $\mu g/m^3$, 41 $\mu g/m^3$, 493 $\mu g/m^3$ and 5 ppm, respectively (Table

1). The concentrations of particulate matter were substantially higher at the roadside than journey-time values, whereas the mean levels of CO were higher inside the vehicle than at the roadside.

Table 1. Summary statistics for in vehicle journey-time, roadside and background concentrations of PM_{10}, $PM_{2.5}$, PM_1 ($\mu g/m^3$) and CO (ppm) for routes I and II in Lahore.

Journey time route I					
	PM_{10}	*$PM_{2.5}$*	*PM_1*	*$PM_{10-2.5}$*	*CO*
Mean	74	36	27	38	9
Maximum	111	71	49	76	18
Minimum	39	17	11	16	2
St Dev	20	17	14	19	5
Roadside route I					
Mean	583	90	41	493	5
Maximum	2756	327	90	2428	11
Minimum	127	35	18	92	1
St Dev	619	71	21	550	3
Journey time route II					
Mean	128	62	48	66	7
Maximum	307	116	83	191	16
Minimum	55	27	21	20	4
St Dev	60	20	15	47	3
Roadside route II					
Mean	404	92	62	312	4
Maximum	1031	168	116	897	11
Minimum	199	45	30	104	1
St Dev	218	30	20	196	2
Overall Journey time					
Mean	103	50	38	53	8
Maximum	307	116	83	191	18
Minimum	39	17	11	16	2
St Dev	53	23	18	39	4
Overall Roadside					
Mean	489	91	52	397	4
Maximum	2756	327	116	2428	11
Minimum	127	35	18	92	1
St Dev	455	53	23	408	3
Background					
Mean	192	58	41	134	
Maximum	378	102	69	276	
Minimum	86	27	17	59	
St Dev	87	28	20	60	

For route II, the mean journey-time concentrations of PM_{10}, $PM_{2.5}$, PM_1, $PM_{10\text{-}2.5}$ and CO were 128 μg/m^3, 62 μg/m^3, 48 μg/m^3, 66 μg/m^3 and 7 ppm, respectively. Those at the at the roadside on route II were 404 μg/m^3, 92 μg/m^3, 62 μg/m^3, 312 μg/m^3 and 4 ppm, respectively (Figure 2). Similar to route I the levels of particulate matter were higher at the roadside than during the journey-time whilst CO concentrations were higher for the journey-time in comparison to the roadside locations. The level of coarse particles was higher on route I while the fine fraction (PM_1) was higher on route II.

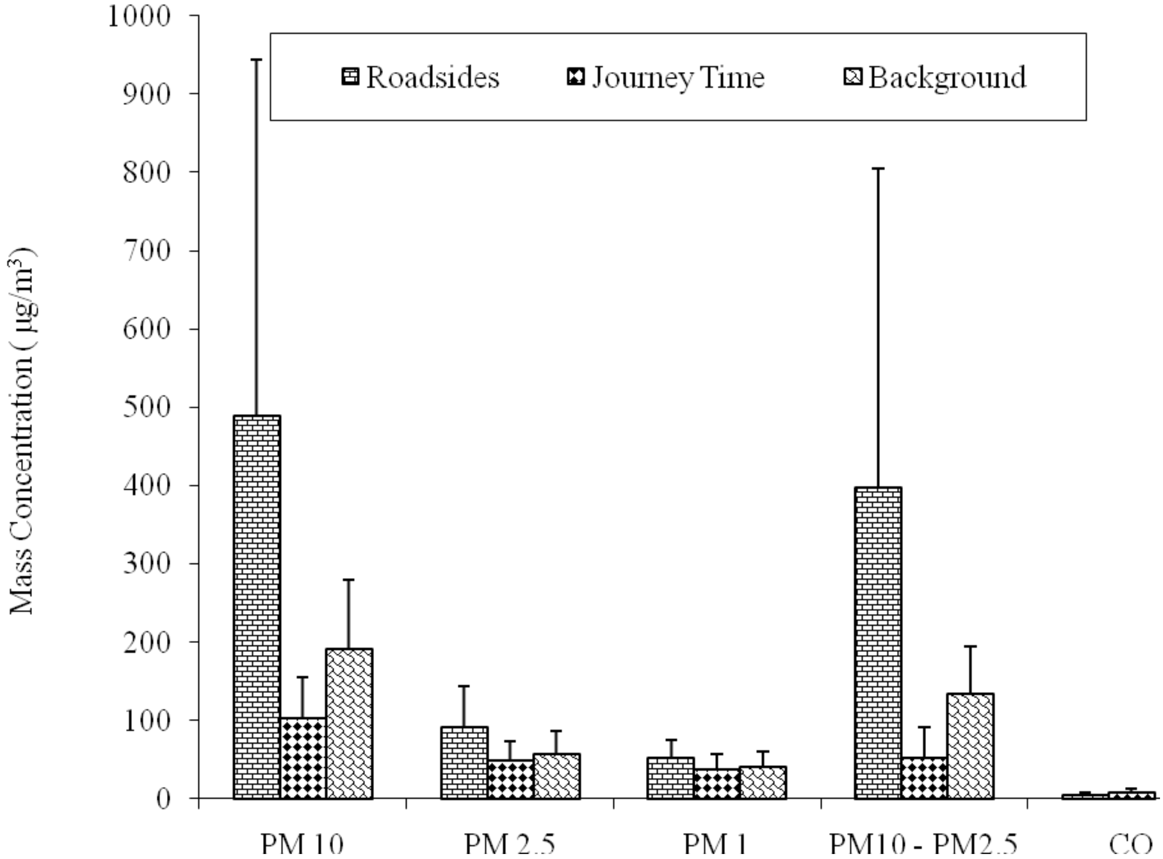

Figure 2. Overall roadside, journey time and background levels of PM_{10}, $PM_{2.5}$ PM_1 (μg/m^3) in Lahore.

Both routes exhibited higher particulate matter levels and lower CO concentrations at the roadside than in vehicles. Most of the particulate matter was found to be in the coarse fraction. For routes I and II PM_{10}, at the roadside was more than 6 and 2 times higher than journey time levels. 84%, 77% and 81% of the total accumulative mass of particulate matter was in the coarse size ($PM_{10-2.5}$) at the roadside for routes I, II and overall, respectively. Similarly, the percentage in the coarse size during journey time was almost 50% for both routes. It should be remembered that journey time levels in this study reflect concentrations in an air-conditioned vehicle where the ventilation system was able to remove the coarse fraction particles. Overall, for finer particles (PM_1) there is little difference between journey time and roadside concentrations (38 $\mu g/m^3$ journey time average vs 52 $\mu g/m^3$ roadsides).

CO showed an accumulating behaviour inside the vehicle, thus levels were higher during the journey time than at the roadside. The maximum journey-time levels of CO were 18ppm as compared to 11ppm at the roadside. This trend is most probably due to the vehicle type (air-conditioned). In general, there was a large variation in the concentration of particulate matter between the different roadside locations and this is evident from the high standard deviation values, whereas the journey-time concentrations of particulate matter were characterized by lower standard deviation values (Figure 2). However, CO levels were more variable during journey times than at the roadside. At the start of each journey CO levels in the vehicle were lower than outside but built up during the journey.

The mean levels of PM_{10}, $PM_{2.5}$, PM_1 and PM_{10} – $PM_{2.5}$ at the background site were 192 $\mu g/m^3$, 58 $\mu g/m^3$, 41$\mu g/m^3$ and 134$\mu g/m^3$, respectively. CO was below the detection limit. Background PM_{10} concentrations were considerably lower than at the roadside although PM_1 levels were similar. This shows that although the coarse size fraction dominates near busy urban sites, the fine fraction can be transported further away from the sources. PM_{10} levels at the background site (192 $\mu g/m^3$) were close to the mean annual for Lahore (202 $\mu g/m^3$) reported by the World Bank (2006).

The roadside levels of particulate matter in this study are lower than those reported by Jafary and Faridi (2006) from 23 road crossings in Lahore (760 – 5,044 μg/m^3). This is more likely due to the reason that they measured TSP. However, concentrations of CO in this study are in good agreement with Jafary and Faridi (2006). Their reported concentrations of CO were 5 to 11 ppm compared to 1 to 11 ppm in this study. . Furthermore, journey-time levels of PM in this study were lower than RSP concentrations (in-car) reported by Saksena *et al*. (2007) for Delhi. It was not mentioned if the car was air-conditioned and the present discrepancy might be due to this or to differences in size cut of measured PM, as their reported mean levels of CO in the car (10ppm) were close to those in this study. Shen *et al.* (2010) reported that levels of PM_{10} at the roadside in Xi'an (China) ranged from 337.9 to 718.0 μg/m^3, with an average of 569.2 μg/m^3. In Nepal, a study by Sharma et al. (2002).showed that roadside hourly PM_{10} was in the range 1,000 to 6,000 μg/m^3.

The levels of $PM_{2.5}$ and PM_1 reflect the contribution from automobile exhaust and, as has been previously mentioned, this would contribute more to number concentration than mass. Nevertheless, the measured levels of $PM_{2.5}$ at the roadside and in vehicle were much higher than the WHO guideline value of 25 μg/m^3 per 24 hours (World Health Organisation, 2006). Similarly, the PM_{10} concentrations were considerably higher than the WHO guideline value of 50 μg/m^3. The results suggest that although the biggest portion of suspended particulate matter was in the coarse-size fraction, the levels of the fine size fraction were also elevated. In fact the levels at the background site were well above any established standard.

The coarse fraction particulate matter was very likely due to the resuspension of road dust by wind and vehicle induced turbulence. This process has been reported in previous studies (Abu-Allaban *et al*., 2003; Braaten *et al*., 1990; Hall, 1989; Kulmala *et al*., 1986). Dust builds up at the kerbside and visible dust particles were clearly seen flowing rapidly in the direction of the traffic flow. The pavements were devoid of any vegetation. Large number of vehicles and poor traffic management often result in traffic congestion. Furthermore, most of the vehicles were poorly maintained and inefficient fuel usage results in excessive exhaust emissions. The concentrations in this study were well above any established ambient air quality standards in the world. The majority of public transport vehicles in Lahore are not air-conditioned and it is very likely that commuters are exposed to very high levels of pollution. A large number of people commute by two or three wheelers and thus they will have the highest exposure. The present study revealed that there is a dire need to adopt air quality standards and strict emission control regulations. The present road system in cities cannot cater for the need of the growing number of automobiles and the problem is being aggravated by an aging vehicle fleet, in poor mechanical condition and low levels of fuel efficiency. Improved traffic planning and the introduction of a better mass transit system in the city could help arrest the soaring levels of carbon monoxide and particulate matter.

REFERENCES

Abu-Allaban, M., Gillies, J.A., Gertler, A.W., Clayton, R. and Proffitt, D. (2003). Tailpipe, resuspended road dust, and brake-wear emission factors from on-road vehicles. *Atmos. Environ*. . 37:5283-5293.

Adams, H.S., Nieuwenhuijsen, M.J., Colvile, R.N., McMullen, M.A.S. and Khandelwal, P. (2001). Fine particle (PM2.5) exposure levels in transport microenvironments, London, UK. *Sci. Total Environ.* 279:29-44.

Akbar, S. and Ashmore, M.R. (1997). Particulate air pollution and respiratory morbidity in Delhi, and its implications. In: Proceedings of the World Congress on Air Pollution in Developing Countries, Costa Rica, Volume II, 52-58. Imprenta Nacional of Costa Rica, San Jose.

Asian Development Bank (2008).Proposed Technical Assistance Loan Islamic Republic of Pakistan: Preparing the Lahore Rapid Mass Transit System Project. Project Number: 40573.

Aerosol and Air Quality Research **11** (2011) pp.689-695.

Bevan, M.A.J., Proctor, C.J., Baker – Roger, J. and Warren, N.D. (1991). Exposure to carbon monoxide, respirable suspended particulates and volatile organic compounds whilst commuting by bicycle. *Environ. Sci. Technol*. 25:788-791.

Braaten, D.A., Paw, U. and Shaw, R.H. (1990). Particle resuspension in turbulent boundary layer—observed and modelled. *J. Aerosol Sci*. 21:613–628.

Briggs, D.J., De Hoogh, K., Morris, C. and Gulliver, J. (2008). Effects of travel mode on exposures to particulate air pollution. *Environ. Int*. 34:12-22.

Briggs, D., Gulliver, J. and De Hoogh, K. (2006). Personal exposures to traffic-related air pollution while walking and in the car: Implications for the assessment of intake fractions. *Epidemiology*. 17:S29-S29.

CAI-Asia (2008a) Air quality and climate change in Asia. Available at: http://www.cleanairnet.org/caiasia/1412/articles-59689_Asia_AQ.pdf

CAI-Asia (2008 b) Clean Air in Pakistan: Summary of progress on improving air quality. Available at: http://www.cleanairnet.org/caiasia/1412/articles-70822_Pakistan.pdf

Chan, L.Y., Lau, W.L., Zou, S.C., Cao, Z.X. and Lai, S.C. (2002a). Exposure level of carbon monoxide and respirable suspended particulate in public transportation modes while commuting in urban area of Guangzhou, China. *Atmos. Environ*. 36:5831-5840

Chan, L.Y., Lau, W.L., Lee, S.C. and Chan, C.Y. (2002b). Commuter exposure to particulate matter air pollution in public transportation modes in Hong Kong. *Atmos. Environ*.36:3363-3373.

Colbeck, I., Nasir, Z.A. and Ali, Z. (2010). The state of ambient air quality in Pakistan—a review. *Environ. Sci. Pollut. Res*. 17:49 - 63.

Franklin M, Zeka A, Schwartz J. (2007). Association between PM2.5 and all-cause and specific-cause mortality in 27 US communities. *J. Expo. Sci. Environ. Epidemiol*. 17: 279-287.

Gee, I.L. and Raper, D.W. (1999). Commuter exposure to respirable particles in buses and by bicycle. *Sci. Total Environ.* 235:403-405.

Geiss, O., Barrero-Moreno, J., Tirendi, S. and Kotzias, D. (2010). Exposure to particulate matter in vehicle cabins of private cars. *Aerosol Air Qual. Res.* 10: 581–588.

Gulliver, J. and Briggs, D.J. (2007). Journey-time exposure to particulate air pollution. *Atmos. Environ*. 41:7195-7207.

Gurjar, B.R., Butler, T.M., Lawrence, M.G., Lelieveld, J. (2008). Evaluation of emissions and air quality in megacities. *Atmos. Environ*. 42:1593-1606.

Government of the Punjab (2010). Punjab Gateway, Government of the Punjab. Available at http://pportal.punjab.gov.pk/portal/portal/media . Accessed on 15 December, 2010.

Gurjar. B.R., Jain, A., Sharma, A., Agarwal, A., Gupta, P., Nagpure, A.S.and Lelieveld J. (2010). Human health risks in megacities due to air pollution. *Atmos. Environ.* 44, 4606-4613.

Hall, D. (1989). The time dependence of particle resuspension. *J. Aerosol Sci*. 20: 907–910.

Hopke, P.K., Cohen, D.D., Begum, B.A., Biswas, S.K., Ni, B.F., Pandit, G.G., Santoso, M., Chung, Y.S., Davy, P., Markwitz, A., Waheed, S., Siddique, N., Santos, F.L., Pabroa, P.C.B., Seneviratne, M.C.S., Wimolwattanapun, W., Bunprapob, S., Vuong, T.B., Hien, P.D. and Markowicz, A. (2008). Urban air quality in the Asian region. *Sci. Total Environ*. 404:103-112.

Jafary, Z.A. and Faridi, I.A. (2006). Air pollution by roadside dust and automobile exhaust at busy road crossings of Lahore. *Pak. J.Physiol*. 2:31 – 34.

Kaminsky, J.A., Gaskin, E.A.L.M., Matsuda, M. and Miguel, A.H. (2009). In-cabin commuter exposure to ultrafine particles on commuter roads in and around Hong Kong's Tseung Kwan O Tunnel. *Aerosol Air Qual. Res.* 9: 353-357

Aerosol and Air Quality Research **11** (2011) pp.689-695.

Kojima, M., Brandon, C. and Shah, J. (2000). *Improving urban air quality in South Asia by reducing emissions from two-stroke engine vehicles*. The International Bank for Reconstruction and Development/The World Bank. 1818 H Street, N.W. Washington, D.C. 20433, U.S.A.

Kulmala, M., Riihiluoma, V. and Raunemaa, T. (1986). Particle emission from gasoline powered vehicles: emission deposition and re-emission under different traffic density situation. *J. Aerosol Sci*. 17: 973–983.

Mukherjee, A.K., Bhattacharya, S.K., Ahmed, S., Roy, S.K., Roychowdhury, A. and Sen, S. (2003). Exposure of drivers and conductors to noise, heat, dust and volatile organic compounds in the state transport special buses of Kolkata city. *Transportation Res. Part D: Transport and Environment*. 8: 11-19.

Nasir, Z.A. and Colbeck, I. (2009). Particulate air pollution in transport micro-environments. *J. Environ. Monit*.11:1140-1146.

Pakistan Economic Survey. (2009-10). Population labour force and employment. Ministry of Finance, Government of Pakistan.

Pope, C.A. and Dockery, D.W. (2006). Health effects of fine particulate air pollution: Lines that connect. *J. Air & Waste Manage. Assoc.* 56: 709–742

Pramal, G. and Schierl, R. (2000). Dust exposure in Munich public transport – A comprehensive 4 yr survey in buses and trams. *Int. Arch. Occup. Environ. Health*73:209 – 214.

Saksena, S., Prasad, R.J. and Shankar, V.R. (2007). Daily exposure to air pollutants in indoor, outdoor and in-vehicle micro-environments: A Pilot study in Delhi. *Indoor Built Environ*. 16:39-46.

Sharma, T., Rainey, R.C., Neumann, C.M., Shrestha, I.L., Shahi, K.B., Shakya, A and Khatri, S. (2002) Roadside particulate levels at 30 locations in the Kathmandu Valley, Nepal. *Int. J. Environ. Pollut.* 17:293-305.

Aerosol and Air Quality Research **11** (2011) pp.689-695.

Shen, Z., Han, Y., Cao, J., Tian, J., Zhu, C., Liu, S., Liu, P.and Wang, Y. (2010).Characteristics of traffic-related emissions: A case study in roadside ambient air over Xi'an, China. *Aerosol Air Qual. Res.* 10: 292–300.

United Nations Population Division (2009) Department of Economic and Social Affairs of the United Nations Secretariat, World Urbanization Prospects: The 2009 Revision Population Database. Available at: http://esa.un.org/wup2009/unup/.:

World Bank (2006). *Pakistan: Strategic Country Environment Assessment.* Volume II. Report No. 36946-PK. Washington, DC: World Bank.

World Health Organisation (2006). Air Quality Guidelines Global Update 2005. WHO Regional Office for Europe. Scherfigsvej 8, DK-2100 Copenhagen O, Denmark.

World Health Organization (2007). Estimated Deaths & DALYs attributable to selected environmental risk factors by WHO member state in 2002. Available at: http://www.who.int/quantifying_ehimpacts/countryprofilesebd.xls

Zanobetti, A. and Schwartz J. (2009). The Effect of Fine and Coarse Particulate Air Pollution on Mortality: A National Analysis. *Environ. Health Persp.* 117: 898-903.