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Exposure to Carbon Monoxide while Commuting in Popular Modes of Transport in Karachi, Pakistan

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Abstract. Motor vehicles are the single largest source of toxic carbon monoxide in Karachi because advance emission control devices are not fitted in them mainly due to non-availability of low sulfur or sulfur-free fuel. On the contrary, commuters' exposure to carbon monoxide has not yet been investigated, while commuting in any motor vehicle of the city. Therefore, the present study investigated commuter's exposure to carbon monoxide, while travelling in nine different popular modes of transport. The exposure to CO concentrations was recorded inside the buses of seven standard routes of the city. Similarly, exposure to ambient carbon monoxide was also explored, while riding a motorbike on two different routes of the city. On an average, he came in contact with 6.82 ± 2.66 ppm CO during 7576 minutes travelling on nine routes of the metropolis. He was exposed to the highest CO concentration (15.20 ± 9.59 ppm), while riding a motorbike through Route 1 that passed through heavily populated neighborhood. Rider's exposure to carbon monoxide was found significantly ($p < 0.05$) correlated with wind velocity. As a whole, commuter's exposures to carbon monoxide during evening was significantly ($p < 0.01$) higher than those of the morning sessions. The present study will provide baseline information for reducing human exposure to the deadly carbon monoxide.

Keywords: carbon monoxide, commuter, exposure, bus, motorbike, Karachi

Introduction

Carbon monoxide is one of the most ubiquitous and toxic air pollutants. It causes wideranging physiological dysfunction in humans mainly because of its binding affinity towards hemoglobin. Its affinity to combine with hemoglobin is 210 times greater than that of oxygen (Prockop and Chichkova, 2007), which instigates the deficiency of oxy-hemoglobin and the upsurge in carboxy hemoglobin level in human blood. Low level and long-term human exposure to carbon monoxide causes headache, fatigue and exhaustion (Townsend and Maynard, 2002) and the higher human exposure to carbon monoxide substantially decreases oxy-hemoglobin in blood, which may risk human life by reducing oxygen supply to the vital organs primarily brain and heart (Liu *et al*., 2018; Sircar, *et al*., 2015; Blumenthal, 2001).

Before the advent of emission control technologies, motor vehicles were the single largest source of ambient carbon monoxide during 1960s and 1970s, even in the most developed countries of the world (Cullis and Hirschler, 1989; Stedman, 1989). Motor vehicles without emissions control device accounted for more than 90% of total man-induced CO emissions (Cullis and Hirschler, 1989). Chan *et al*., (1992) has reported that motor vehicles had contributed about 98% of total CO emissions in Taipei, Taiwan; of which motorcycles accounted for nearly 44% of total CO emissions.

The gradual application of various emission control technologies through different emission control standards has greatly reduced its emission from motor vehicles in developed countries over the years (Bradley *et al*., 1999). However, high sulfur fuel in many developing countries restricts the application of advance emission control technologies in their motor vehicles. Moreover, the developing countries have larger proportion of old and poorly maintained motor vehicles compared to affluent countries, which increase the ambient carbon monoxide (Bradley *et al*., 1999). The studies suggest that the motor vehicles emit greater carbon monoxide in the developing countries.

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Consequently, many studies have been conducted to divulge the human exposure to carbon monoxide during commuting in different modes of transport over the last few decades; earlier in the developed countries and later in the developing countries (Alhajeri *et al*., 2018; Odekanle *et al*., 2017; Potcher, *et al*., 2014; Both *et al*., 2013; Huang, *et al*., 2012; El-Fadel and Abi-Esber, 2009; Duci *et al*., 2003; Chan and Liu, 2001; Dor, *et al*., 1995; Fernanzed-Bremauntz and Ashmore, 1995; Ott *et al*., 1994; Koushki *et al*., 1992; Flachsbart *et al*., 1987; Petersen and Allen, 1982; Brice and Roesler, 1966).

However, commuters' exposure to carbon monoxide has not been explored in Karachi, while commuting in motor vehicles. Available studies have demonstrated (CO) concentrations along the streets and their intersections (Shareef *et al*., 2011; Shams and Beg 2001). Shabzwari and Fatimi (2011) compared exhaled carbon monooxide (CO) levels among commuters and street vendors in urban and sub urban population of the metropolis.

The drivers and commuters are exposed to many air pollutants, which are generated from various sources in urban area. However, motor vehicles are the main source of carbon monoxide, particularly motorists commute on the busy roadways and streets of urban neighbourhoods. Therefore, the present study investigated commuters' exposure to carbon monoxide, (CO) while commuting in public transports, which were operating in Karachi. Moreover, motorbike riders' exposure to ambient carbon monoxide was also explored, while riding through major streets of the city since motorbikes constitute 56.66% of the total number of registered motor vehicles operating in Karachi (Infonalysis, 2017).

Materials and Methods

Study Area. Karachi is located at 24° 45′ N to 25°37′ N and 66° 42′ E to 67° 34′ E along the shoreline of Arabian sea. It is the most populous metropolitan city of Pakistan and sixth most populous city of the World. Presently, 20 million people reside in the city, which sprawls over an area of 3,530 Km^2 (Karachi Metropolitan Corporation, 2018). The city is financial hub of the country and is ranked as World's beta city (GaWC, 2010). It produces about two-third revenue for the country. The city has 4.13 million registered motor vehicles; of which motorcycles constitute 2.34 million, motorcars 1.32 million, three-wheeler rickshaws 0.23 million, trucks and tankers 40 thousand, while passenger buses, minibuses and coaches constitute 23 thousand (Infonalysis, 2017). The study area is classified as arid hot desert (Kottek *et al*., 2006). It receives low rainfall (annual average, 250 mm). Its air temperature ranges between 13 °C to 36 °C.

In this study, carbon monoxide was measured by data logger EL-USB-CO300 of Lascar Electronics Ltd., United Kingdom. The device has an electrochemical sensor, which continuously monitors and stores CO concentration that ranges between 0 to 300 ppm with a resolution of 0.5 ppm. It operates between -10 °C to 40 °C with an accuracy of ±4%. The data logger was interfaced with computer through EasyLog software to record CO concentration with one-minute interval.

In vehicle exposure to carbon monoxide was measured while commuting as passenger in seven standard routes of four different types of popular public transport in Karachi, namely coach, micro-bus, mini-bus and bus (Fig. 1). Three coaches (MashaAllah, Muslim and New Afridi) and two mini-buses (W-11 & G3) were selected for the commuter's exposure to carbon monoxide. These buses are the most popular mode of transport in the city.

All the coaches and mini-buses were 26-seater. The coaches were fast moving and had at fewer stops, while mini-buses were slow moving and stopped anywhere along their route for boarding and un-boarding of passengers. One micro-bus (N-5, 12-seater) and one bus (11-C, 40-seater) were selected for commuter's exposure since they are fewer in number in the city. However, all the public buses under study boarded passengers beyond their capacity. Sometimes, rooftops of the buses were used for accommodating the commuters. Overloading of public transports is very common primarily due to their shortage in the city. All the buses were non-air-conditioned. Their windows were opened because the experiments were performed during summers.

The commuter, who was subjected to record his exposure to inside carbon monooxide (CO) concentration in this study, was seated just behind the bus driver. The data logger was firmly attached to the collar of the commuter once the vehicle had started to move. The device was removed after the completion of journey. All the routes of buses originated from different sub urban areas and terminated in downtown of the city. Only urban part of each route was selected for his exposure to carbon monoxide, while sub urban part was excluded from the study.

The duration of each trip varied due to different route length and the speed of the motor vehicle that was mainly due to traffic congestion. Every trip of each route was replicated three times for the collection of exposure data with maximum accuracy. After completion of every trip, the device was interfaced with computer to transfer the data for statistical analysis.

Similarly, motorbike rider's exposure to ambient carbon monoxide was also measured while riding on major routes of the city. In this study, two different routes were selected for rider's exposure to carbon monoxide (Fig. 1). All the exposures were recorded during peak traffic hours of twelve working days on two distinct routes. The exposures to carbon monoxide were recorded during 9:00 - 11:00 a.m. in the morning and 5:00 - 7:00 p.m. in the evening since the durations are the peak traffic hours in Karachi.

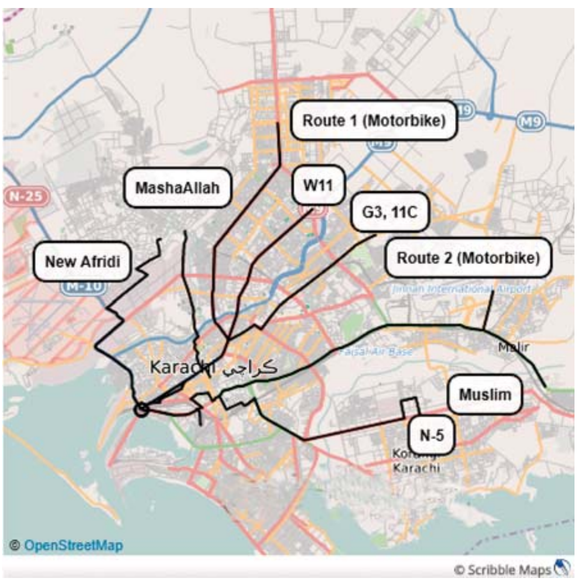

Fig. 1. Study routes in Karachi.

F-test was performed to reveal whether the means of carbon monooxide (CO) concentrations during morning and evening sessions significantly differ or not inside the public transport. The test was also carried out to make known whether the means of ambient carbon monoxide during morning and evening sessions statistically differ or not, while riding motorbike on two different routes of Karachi. Pearson productmoment correlation was performed to divulge whether the motorbike rider's exposures to ambient carbon monoxide were significantly correlated or not with wind velocity.

Results and Discussions

A total of 7576 readings of commuter's exposure to carbon monoxide was recorded while travelling 7576 minutes in nine different modes of transport in Karachi since the device was set to measure the data with one-minute interval (Table 1). 4200 readings were recorded during evening session, while 3376 readings were logged during morning session. It is important to note that equal distances were travelled during both the sessions but greater time was consumed during evening mainly due to slow pace of traffic and its congestion.

The overall results demonstrate that the commuter was exposed to 6.82 ± 2.66 ppm of CO on an average, while commuting in nine different modes of transport in Karachi (Table 1). He was exposed to the highest average CO concentration (15.20 ± 9.59 ppm) while riding a motorbike along Route 1. He came in contact with the lowest average CO concentration (2.00 ± 8.70 ppm) on the Route 2 of motorbike. He was exposed to the highest average CO concentrations in both the morning (21.56 ± 10.09 ppm) and the evening (8.83 ± 1.49 ppm) sessions, while riding a motorbike along Route 2.

The commuter's exposure to CO concentration inside the buses of seven different routes of the city reveals that he came in contact with the highest average CO concentration (9.01 ± 5.19 ppm) in W-11 minibus, which was followed by his exposure to 8.53 ± 6.07 ppm of carbon monoxide in MashaAllah coach. On the contrary, he experienced the lowest average CO concentration (4.32 ± 3.08 ppm) in New Afridi coach.

During seven morning sessions, the commuter inside the bus came in contact with the highest average CO concentration (6.34 ± 4.12 ppm), while travelling in MashaAllah coach, which was followed by his exposure to 6.28 ± 2.97 ppm in W11 minibus. On the contrary, he was exposed to the lowest average CO concentration (3.62 ± 2.32 ppm) during morning session of New Afridi coach. During seven evening sessions, he was exposed to the highest average CO concentration (10.55 ± 5.54 ppm) inside W11 minibus, which was followed by his exposure to 9.87 ± 6.65 ppm in MashaAllah coach. Nonetheless, during evening sessions, he

Table 1. Commuters' exposure to carbon monoxide while commuting in different modes of transport in Karachi

Route & vehicle's capacity	Route length (km)	Number of samples (n)	Mean ± SD	Trips	Sampling (n)	Mean ± SD	F-test Value
Masha Allah (26-seater)	17.0	907	8.53 + 6.07	Morning Evening	344 563	6.34+4.12 9.87+6.65	0.000
N-5 (12-seater)	18.0	750	4.71 + 2.95	Morning Evening	356 394	4.43 +2.89 4.97+2.98	0.540
W-11 (26-seater)	15.5	718	9.01 + 5.19	Morning Evening	259 459	6.28+2.97 10.55+5.54	0.000
Muslim (26-seater)	25.0	660	6.69 + 3.99	Morning Evening	355 305	6.05+3.65 7.44+4.24	0.007
11-C (40-seater)	13.0	511	5.85 + 2.92	Morning Evening	200 311	5.40+3.02 6.13+2.82	0.259
G-3 (26-seater)	13.0	552	5.07 + 2.26	Morning Evening	241 311	3.65+2.26 5.25+2.19	0.007
New Afridi (26-seater)	15.0	283	4.32 + 3.08	Morning Evening	126 157	3.62+2.32 4.89+3.49	0.000
Motorbike (route 1)	20.00	1771	15.20 + 9.59	Morning Evening	809 962	8.83 + 1.49 21.56 + 10.09	0.000
Motorbike (route 2)	23.00	1424	2.00 + 8.70	Morning Evening	686 738	1.89 + 8.00 2.09 + 9.30	0.006
Total	---	7576	6.82 + 2.66	Morning Evening	3376 4200	5.17 + 1.89 8.08 + 2.88	0.008

experienced the lowest average CO concentration (4.89 ± 3.49 ppm) inside New Afridi coach.

The commuter's exposure to CO concentration, while commuting during evening sessions in all the 26-seaters, was significantly higher ($p < 0.001$) than those of the morning sessions (Table 1). However, no statistical difference was found between the mean CO concentrations of morning and evening sessions of N-5 (12-seater) and 11-C (40-seater). As a whole, the commuter's exposures to CO concentration during evening sessions were significantly ($p < 0.01$) greater than those of the morning sessions.

Figure 2 demonstrates the commuter's exposure to average CO concentration while travelling in five different popular modes of transport in Karachi during morning and evening sessions. The figure demonstrates that motorbike rider was exposed to the highest average

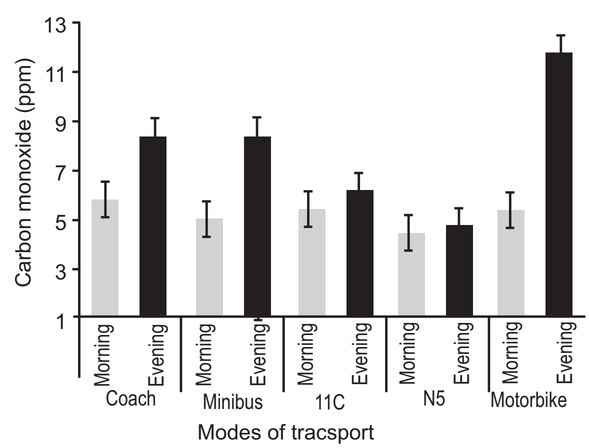

Fig. 2. Commuters' exposure to average CO concentration while commuting during morning and evening in different modes of transport in Karachi

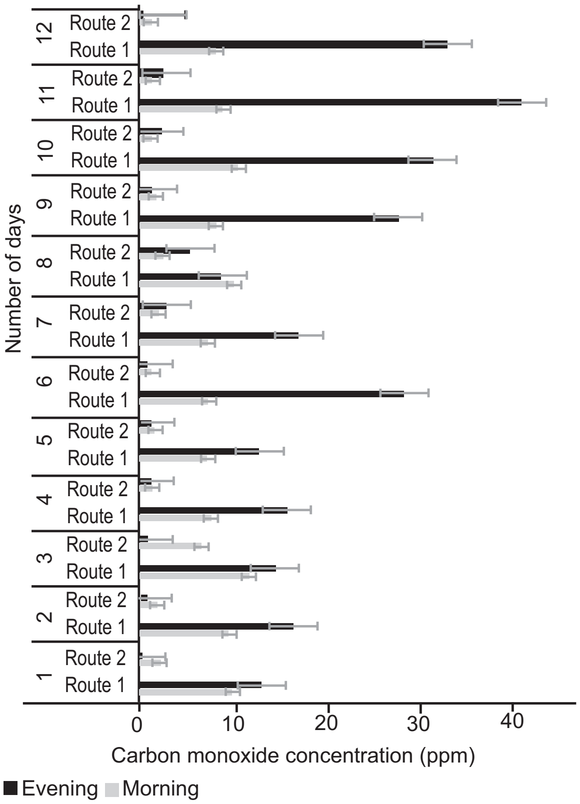

Fig. 3. Rider's exposure to average carbon monooxide (CO) concentration while riding a motorbike during morning and evening traffic peak hours of different days through two major routes in Karachi.

CO concentration, while riding during evening sessions. Figure 3 divulges that motorbike rider's exposures to average CO concentration while riding a motorbike during morning and evening sessions of twelve days through two different routes of Karachi. The rider's exposure to carbon monoxide was significantly greater ($p < 0.01$) on Route 1 compared to those on Route 2. Statistically significant ($p < 0.05$) correlation was found between rider's exposure to ambient carbon monoxide and the wind velocity.

The results reveal that the commuter was exposed to lower average CO concentration inside the vehicles, while travelling in different modes of transport in Karachi compared to those of many mega cities of the world (Both *et al*. 2013; Colbeck *et al*. 2011; Duci, *et al*., 2003; Fernanzed-Bremauntz, *et al*., 1995; Koushki *et al*., 1992). However, its average concentrations inside the buses of Karachi were higher than those of some other cities (Huang *et al*., 2012; Chan and Liu, 2001). It is worth mentioning that all the buses of the present study were more than twenty years old. They did not have any emission control device. Nonetheless, all the buses were powered through compressed natural gas (CNG). Presently, compressed natural gas is the most widely used fuel to propel the motor vehicles in Karachi (Pakistan Energy Year Book 2017). According to the NGV joint report 2012, Pakistan has second biggest fleet of CNG operated vehicles in the world. The commuter's exposure to lower CO concentration inside the buses of Karachi was primarily due to greater number of CNG powered vehicles than that of gasoline and diesel powered vehicles. It is important to state that CNG powered vehicles emit significantly lower carbon monoxide compared to gasoline powered vehicles (Jahirul *et al*., 2010).

Nevertheless, the commuters in Karachi came in contact with higher average CO concentration, while travelling during evening traffic peak hours than those during morning peak hours. During evening peak hours, greater fuel was burned to drag the motor vehicles due to congestion and slow pace of vehicular traffic, which caused greater emissions of carbon monoxide. The traffic congestions were mainly due to the presence of roadside vendors, hawkers and motor mechanic shops during evening hours. The parking of motor vehicles along most of the main roads of the city also reduced its width from both the sides and obstructed the smooth flow of vehicular traffic. Stop and start conditions of the motor vehicles were prevalent in the downtown areas of the city. Moreover, the traffic flow further suffered the loss of its pace due to loading and offloading of passengers of public transports anywhere along their routes due to absence of proper bus stops in the city.

In the morning, majority of roadside vendors and shops were closed. In many areas of the city, motor vehicles were found thinly parked along roadsides in the morning since major markets of Karachi started opening after 11:00 a.m., that is, after the termination of our morning session study.

The commuter was exposed to the highest CO concentrations inside W11 minibus since it passes through the most populated and congested streets of central towns of Karachi. Furthermore, the streets of central city area, particularly the streets' intersections, were largely occupied by roadside vendors, shops and parking of motor vehicles, particularly during evening. Moreover, a large number of public and private motor vehicles surge the area, while moving from one end to another end of the city. The commuter came in contact with the lowest CO concentrations inside New Afridi coach because it runs on the streets of peripheral towns of the city.

Similarly the motorbike rider was subjected to the highest ambient carbon monoxide while riding on Route 1, which passes through the most inhabited central towns of the city, while he was exposed to the lowest ambient carbon monoxide on Route 2, which was on the southern periphery of the city. Motorbike rider was exposed to higher CO concentration compared to the commuter of buses in Karachi. This may because the motorbikes in Karachi are gasoline powered. Moreover, they directly faced the tailpipe exhausts of other motor vehicles. Furthermore, the rider's exposure to carbon monoxide increases rapidly due to calm wind conditions since his exposure to ambient carbon monoxide is significantly correlated with wind velocity.

Conclusion

Roadside hawkers, shops and motor vehicles parking decrease streets' width, which cause traffic congestion particularly in the evening, emit greater carbon monoxide in Karachi. Therefore, the roadside activities should be shifted or at least reduced from heavy traffic areas for reducing commuting time, fuel and emission. Furthermore, fuel sulfur should be gradually reduced so that more stringent vehicular emission standards could be progressively applied to the motor vehicles operating in Karachi. Currently Pakistan could not adopt Euro III or any stringent emission standards for motor vehicles, mainly because of non-availability of low sulfur fuel. Higher emission control standards could only be adopted once the sulfur in the fuel is substantially reduced.

Conflict of Interest. The authors declare no conflict of interest

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