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ENVIRONMENTAL CHEMISTRY, POLLUTION & WASTE MANAGEMENT | RESEARCH ARTICLE

Personal exposures to particulate matter in various modes of transport in Lagos city, Nigeria

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Abstract: Urban air pollution continues to be a major problem in Nigerian cities. Most studies of air pollution in Nigeria have concentrated on the background air quality and its effects on people outside vehicles. However, it has been suggested that in-vehicle pollution is often worse than pollution outside the vehicle. This study focuses on personal exposures to PM_{10} and $PM_{2.5}$ in various modes of transportation in Lagos city. Six roadways which are representative of commercial, industrial, and residential areas of the city were selected. Measurements were made inside four major modes of transportation in the city: cars, buses, Bus Rapid Transit (BRT), and walking for PM_{10} and $PM_{2.5}$. Measurements were done for each mode twice a day (morning and afternoon) for 12 days. The highest average PM_{10} and $PM_{2.5}$ concentrations were measured for pedestrian (476.35 and 216.60 μg/m^3, respectively) during rush hours. The result showed that pedestrians were found to be exposed to the highest average PM_{10} and $PM_{2.5}$ concentrations, while commuters in cars, BRT and buses were exposed to respective decreasing concentrations of PM_{10}. Similarly, commuters in BRT were exposed to the lowest concentrations of $PM_{2.5}$ regardless of time of day. The results obtained were much higher than the results for London but comparable to Mexico city and Taiwan's results. This study has provided information that can help commuters to choose appropriate travel behavior that can minimize their exposure to particulate matter.

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PUBLIC INTEREST STATEMENT

The greatest concern of commuters stuck in traffic is most likely that they would not get to their destination on time. Few people are concerned with the nature of the air quality inside their vehicles. This article assesses personal exposure of commuters to particulate matter in major modes on transport in Lagos city, Nigeria, based on travel time, transport mode, and traffic density. It was found that pedestrians were exposed to highest level of particulate matter compare to those inside vehicles. Regardless of the time of the day, commuters in Bus Rapid Transit are the least exposure to the pollutant as compared those in car and buses. Understanding these can help commuters to choose appropriate travel behavior to reduce their exposure to particulate matter also policy-makers on environmental issues are helped with scientific information necessary for mitigation of public exposure to air pollutants.

Subjects: Environmental Issues; Environment & Health; Environmental Change & Pollution; Sustainable Transport Engineering; Aerosol Science

Keywords: motor vehicle commuters; pedestrian; exposures; particulate matter; PM_{10}; $PM_{2.5}$

1. Introduction

The increase in particulate pollution is a potential human risk. Traffic is a major emission source of particles especially in urban areas (Weijers, Khlystovb, Kosa, & Erismana, 2004). Approximately half of the world's population currently resides in urban centers and the percentage living in rural areas is projected to decline as cities grow into mega-metropolises (O'Neill et al., 2003).

Cities are home to a raft of social and environmental problems, and air pollution is a key issue because of its adverse effects on human health. Although urban pollution originates from a variety of sources, in most urban areas, the transport sector (Colvile, Hutchinson, Mindell, & Warren, 2001), has been identified as a major source of air pollution. Recent study by Daniel, Doris, Stefania, and David (2011) has it that human exposure to air pollution from motor vehicles is increasingly being linked to adverse health outcomes. It is thought that most people receive a significant proportion of their daily air pollution dose while commuting to work, whether this be walking, cycling, traveling by car or public transport (Dirks, Sharma, Salmond, & Costello, 2012). Owing to its flexibility, road transport is a major transport mode, and cars, minibuses as well as Bus Rapid Transit (BRT) vehicles are objects of desire and pride in many societies. Unfortunately, these positive aspects are closely associated with hazards caused by road transport to the environment and human health (Dora & Phillips, 2000). Although atmospheric particles have been widely studied in different parts of the world, there are limited studies of exposure to particulate matter during transport in Nigeria.

Particulate matter (PM) is a complex mixture typically divided in fractions based on particle size. Coarse particles with diameters less than 10 microns correspond to particles defined as PM_{10}. Fine particles, on the other hand, with diameters less than 2.5 microns are collectively referred to as $PM_{2.5}$ (Tsai, Wu, & Chan, 2008). These particulate matters can be attributed to two major sources. While the first is a natural aerosolization of crustal matter, which includes re-suspended dust from roadways, sea salt, and biological material such as pollen and fungi, the second source is combustion of fossil fuels (Koenig, 2000). Large, dark PM may include smoke and soot from incomplete combustion, though PM may also include dust. Diesel vehicles are a major source of both coarse and fine PM pollution. Particulate matter is arguably the most dangerous component of automobile exhaust (Andrew, Joseph, Trace, & Shala, 2000). Exposure to airborne particulate matter has become a serious public health issue (Cheng, Lin, & Liu, 2008). Both PM_{10} and $PM_{2.5}$ are known as major traffic-related air pollutants in urban environments.

Emission inventories suggest that motor vehicles are the primary direct emission sources of PM to the atmosphere especially $PM_{2.5}$ (Schauer et al., 1996; Yifang, Wiliam, Seongheon, Si, & Constantinos, 2002). There is a consistent relationship between increases in PM exposure and contemporary increases in mortality and morbidity (Schwartz, 1991; Vedal, 1997). Exposure to airborne particulate matter (PM) is of increasing concern to the general public. Several studies conducted over the last decades have revealed that chronic exposure to high levels of respirable particulate matter is closely linked to an increase in respiratory problems, hospital admissions, and mortality (Ostro, 1993; Tony, 1995). Short-term exposure (e.g. while driving) to peak particle concentrations may also be associated with adverse health effects (Delfino, Zeiger, & Seltzer, 1998).

Previous studies revealed that exposure level to particulate matter in traffic microenvironment is influenced by transportation mode (Briggs, de Hoogh, Morris, & Gulliver, 2008; Kaur & Nieuwenhuijsen, 2009), cabin ventilation (Chan, Lau, Lee, & Chan, 2002; Knibbs, Cole-Hunter, & Morawska, 2011), meteorological parameter (Kaur & Nieuwenhuijsen, 2009), route, fuel type, filtration deposition, and Ultrafine Particle penetration (Knibbs et al., 2011). The goal of this study is to assess personal exposure to particulate matter in various modes on transport in Lagos city, Nigeria based on travel time, transport modes, and traffic density. The exposure levels among different modes of transport were compared. Results obtained provided information for commuters on how to choose appropriate travel behavior to minimize personal exposure.

2. Experimental

2.1. Study area

This study was conducted in Lagos city—one of the most important and densely populated urban centers with serious air pollution problems in Nigeria. It is Nigeria's main commercial center, with more than 70% of the nation's industries and economic activities carried out there, which makes it the most economically important urban region of the country (Somuyiwa, 2009). Lagos is located on latitude 6° 22′ and 6° 42′ North and longitude 2° 42′ and 3° 22′ East and has a tropical wet and dry climate with two distinct rainy seasons; the more intense one occurs between April and July, with a milder one from October to November. At the peak of the rainy season, the weather in Lagos is wet about half the time. Lagos experiences a dry season (when it rains less than two days per month) during August and September, as well as between December and March, accompanied by harmattan winds from the Sahara Desert, which are at their strongest from December to early February. The temperature range in Lagos is fairly small, generally staying between 91°F (33°C) and 70°F (21°C). The hottest month is March, when average daytime temperatures reach 84°F (29°C), while July is the coldest month with an average temperature of 77°F (25°C). Lagos has over 224 vehicles per kilometer as against 15 vehicles per kilometer in other states in Nigeria (Awoyemi, Ita, Awotayo, Lawal, & Dienne, 2013); hence heavy traffic congestion is experienced by over 10 million commuters on its roads on a daily basis. Figure 1 shows traffic congestion along two of the selected six routes (Oshodi–Berger and Oshodi–Agege Roads). Lagos Mega city is the sixth largest city in the world, projected to become the third biggest urban conurbation on the planet by the year 2015 (Anthony, 2010). With a population density second only to Bombay in India, Lagos faces enormous challenges of pollution due to its population. Figure 2 shows the map of the study area, the distance for each sampling route is as shown in Table 1.

2.2. Material and method

Particulate matter (PM) concentrations were measured using GT-331, an Aerosol Particle Mass Monitor from the Met One Instruments. It is a hand held, battery operated, and completely portable unit measuring five mass ranges of particulates: PM_1, $PM_{2.5}$, PM_7, PM_{10}, and TSP with a concentration range of 0–1 μg/m^3, a sampling time of 4 min, a flow rate of 2.83 l/min-measured in μg/m^3. To measure, it is switched on in the environment of interest and the measured concentration is read directly on the screen after the particle capturing. At every location of interest, the monitor is placed at least 1 m above the ground level. When in operation, air is drawn in through a small optical orifice, and a laser optical system counts and sizes the particles as they pass through. The pulses from the detector are stored in one of the four memory banks and are converted into mass. A sound of internal vacuum pump indicates the end of a cycle which is then followed by pressing "SELECT" key to display concentration in size ranges on the screen of the monitor. The monitor display the result until the

Figure 1. Traffic congestion along Oshodi–Berger and Oshodi–Agege roads.

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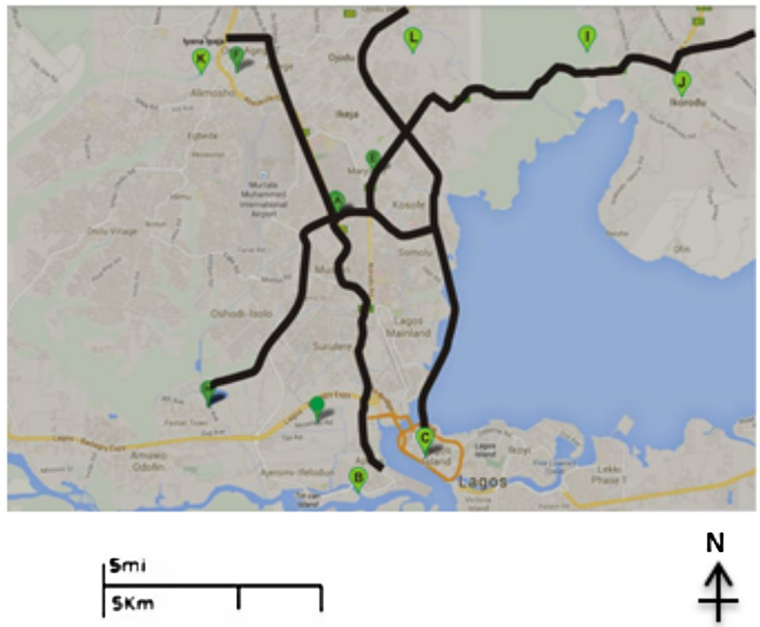

Figure 2. Map of the study area (Google map).

Table 1. Travel distance, travel time, and 12 h one-way average traffic volume

Routes	Travel distance[a] (km)	Travel time (mins)	12 h average traffic volume	
			LAMATA[b]	Monitored
Oshodi–Agege	17.2	39	57,802	81,761
Oshodi–Apapa	16.3	39	127,559	181,260
Oshodi–Mile12	18.1	44	–	65,208
Iyana Ipaja–CMS	26.1	56	–	63,828
Oshodi–Berger	10.4	30	33,291	50,950
Ikorodu–Maryland	21.3	53	57,537	76,980

[a]Source: www.distancesfrom.com.

[b]Source: LAMATA (2002).

"START" key is pressed to begin another cycle of sampling or until the unit is switched off. Any data accumulated are lost when the "STOP" key is pressed.

Six routes selected for this study are Agege Pen–Cinema to Oshodi; Oshodi to Apapa; Oshodi to Mile 12; Oshodi to Berger, Ikorodu to Maryland; and Iyana Ipaja to Church Missionary Society (CMS) road. These routes were chosen because they are representative of typical commuting routes in residential, commercial, and industrial districts in Lagos with high traffic volumes (Table 1). Four researchers (each per mode of transport) were engaged to simultaneously measure the concentrations of particulate matter (PM_{10} and $PM_{2.5}$) on the selected routes (as stated above) in the city during the morning and afternoon commuting periods for people going by car, bus, and BRT vehicles using the equipment described in the section above. All the researchers attended a training session covering the operation of equipment and the schedule of the study. The measurements were taken during dry season for 12 days (beginning from Monday 8 to Saturday 20 of December, 2014, except Sunday 14). Dry season is thought to be a period where particulate matter emission is at its highest. Sampling of in-cabin air during rush hour and non-rush hour of each day was done (designated as morning and afternoon, respectively). The rush hour in-cabin air sampling was done between 07:00 and 10:00 am for rush hours while the non-rush hour sampling was done between 1:00 and 3:00 pm. Measurements were made for both roadway directions and each direction of movement lasted for a minimum of 30 min.

The pollutants monitoring scheme was as follows: First, during rush-hour period, the vehicle was boarded at the pre-determined starting point and the monitors were switched on. At the final destination, the monitors were switched off. For each route, when the vehicle moves in the opposite direction, the monitors were switched on again. These procedures were also repeated during non-rush hour. Pedestrian exposure for a minimum of 30 min on each route was measured. The modes of transport used for this study were not air conditioned hence in all the modes of transport, windows were kept open and there was no air conditioning system. Car and bus were powered by petrol while BRT was powered by diesel. Smoking was prohibited in all public transport modes in this region, hence nobody was found to violate this during the sampling period. The Statistical Package for Social Science (SPSS) program 17.0 was then used for the statistical analysis and testing of the results. Throughout each measurement period, one-way traffic strength on each route, defined by number of vehicles per hour, was continuously monitored by a camcorder (video recorder). After each measurement period (rush and non-rush hour), the videotapes were replayed and traffic volume was counted manually. The number obtained multiplied by 12 gives the 12 h average traffic volume. Table 1 shows the distance of each route, the travel time and the 12 h average traffic volume on each route.

3. Results and discussion

As seen in Table 2, pedestrians were exposed to the highest level of PM_{10} with a mean exposure level and standard deviation of 476.35 ± 48.91 μg/m^3 in the morning and 454.60 ± 51.67 μg/m^3 in the afternoon. These were, respectively, 1.11 and 1.13 times higher than for car users (427.68 ± 41.28 and 400.78 ± 45.60 μg/m^3), 1.23 and 1.43 times higher than for BRT commuters (385.30 ± 97.85 and 316.97 ± 37.54 μg/m^3), and 1.29 and 1.28 times higher than for bus commuters (369.30 ± 30.14 and 355.86 ± 15.36 μg/m^3). Figure 3 reveals that just a few of the measurements recorded in the afternoon for pedestrians fell below the median value. The median is shown by the short horizontal line in each box. The numbers 30, 36, 37, and 43 on Figure 3 indicate code for the concentration that is an outlier in the sample size (e.g. code 30 stands for concentration of 579.25 μg/m^3). While BRT commuters were exposed to the third highest average PM_{10} in the morning, they experienced the lowest average level in the afternoon (Table 2). It is thought that the higher average concentration of PM_{10} in BRT than in bus could be as a result of diesel being the fuel used by BRT, as about 73% of PM_{10} particulates originate from diesel exhaust alone (Kingham & Dorset, 2010).

While these trends and values conform to research conducted by Briggs et al. (2008) and Saksena, Quang, Nguyen, Dang, and Flachsbart (2008), other studies in developing countries have reported the following range of values—Car: 65–140 μg/m^3; Bus: 125–184 μg/m^3; Pedestrian: 55–78 μg/m^3

Figure 3. Box plot showing average PM_{10} levels in various modes of transportation marked by periods.

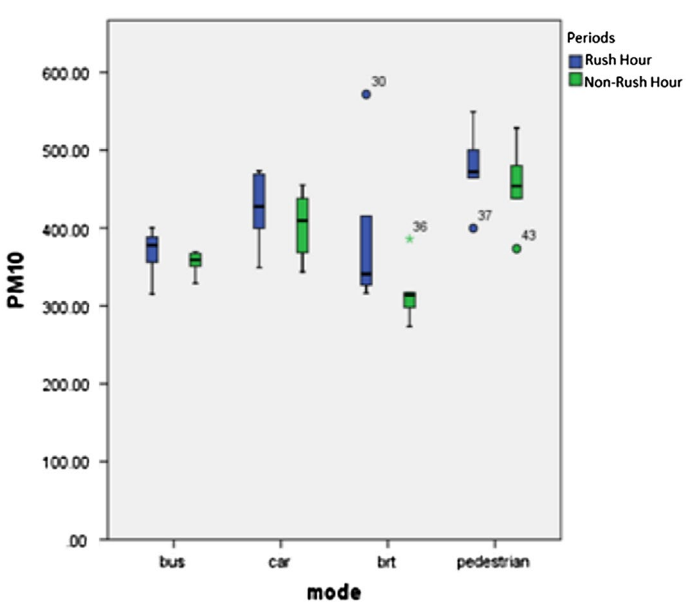

Table 2. Descriptive statistics for PM_{10} concentration (μg/m³) in various modes transportation

	Morning hours (am)						Afternoon hours (pm)					
Modes	**N**	**Mean**	**SD**	**CV (%)**	**Min**	**Max**	**N**	**Mean**	**SD**	**CV (%)**	**Min**	**Max**
Bus	200	369.30	30.14	8.16	325.45	400.14	205	355.86	15.36	4.32	308.81	385.81
Car	200	427.68	41.28	9.65	368.66	473.36	210	400.78	45.60	11.38	359.15	455.02
BRT	200	385.30	97.87	25.40	316.25	571.66	200	316.97	37.54	11.84	273.50	385.91
PDR	198	476.35	48.91	10.27	399.73	529.28	200	454.60	51.67	11.37	373.45	508.49

Notes: N: Sample size; Mean: Arithmetic mean; SD: standard deviation; CV: coefficient of variation; Max: maximum; Min: minimum.

(Chan et al., 2002; Zhao et al., 2004). However, Zhao et al. (2004) observed that pedestrian exposure to PM_{10} was higher than for public transport modes in Guangzhou, China, as revealed by this present research work. The reason for this could be that vehicles are not the only source of PM_{10} as other sources such as dust in suspension near the curb can also contribute. Figures 3 and 4 show that pedestrian exposure level is the highest, though the highest mean concentration difference between morning and afternoon periods was observed for BRT commuters while the lowest mean concentration difference occurred inside the bus. While the inter-modal comparison of the concentrations (Table 3) indicates a statistically significant difference between the concentrations measured for each mode ($p < 0.05$), the inter-period comparison (Table 4) shows similarity for both periods ($p > 0.05$).

The levels of $PM_{2.5}$ for the selected modes of transport were 105.36–258.30 μg/m³ and the highest concentrations were observed during the morning periods (rush hours). As Table 5 shows, the highest average $PM_{2.5}$ concentration was measured for pedestrians (216.60 ± 36.20 μg/m³ for morning and 197.05 ± 37.90 μg/m³ for afternoon periods).

In this study, the average $PM_{2.5}$ personal exposure for pedestrians was found to be much greater than the range of values measured in London (27.7–37.7 μg/m³) (Kaur, Nieuwenhuijsen, & Colvile, 2005), but comparable to the average in Taiwan (214 μg/m³) (Kaur, Nieuwenhuijsen, & Colvile, 2007). This is thought to be due to the different development levels of the two environments. London is in a developed nation with strict vehicular emission control and good road network, while Taiwan (like Nigeria) is a developing nation with no vehicular emission control, but heavy traffic and unpaved curbsides (Kaur et al., 2005, 2007). Hence, a higher concentration of the pollutant is expected since outside emissions are affected by heavy traffic, busy intersections, and meteorology (Asmi et al., 2009; Kaur & Nieuwenhuijsen, 2009). The second highest average $PM_{2.5}$ concentration was recorded inside bus (157.02 ± 22.24 μg/m³ for morning and 142.57 ± 27.14 μg/m³ for afternoon). Previous studies in Hong Kong and Guangzhou (China) and in Mexico city (Mexico) have found average exposure levels for $PM_{2.5}$ in non-air conditioned buses (the same measurement condition as this present study) to be 93–145 μg/m³ during non-rush hour (Chan et al., 2002), and 137–161 μg/m³ during rush hours (Gómez-Perales et al., 2004; Han & Naeher, 2006), which are similar to those obtained in this

Figure 4. Bar chart showing average concentration of PM_{10} in various modes of transportation marked by periods.

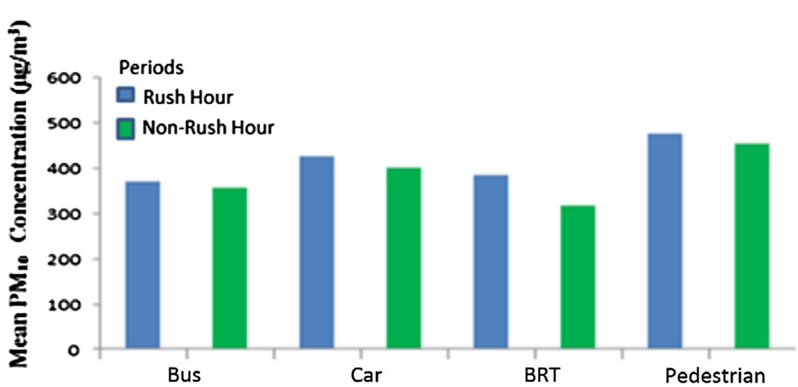

Table 3. *t*-test for paired mean concentration of PM_{10} between the modes of transportation (n = 12)

		Mean	Standard deviation	Mean difference	*df*	*t*	*p*-values
Pedestrian–bus	Pedestrian	465.47	49.29	–	–	–	–
	Bus	362.58	23.86	102.89	22	6.508	0.0001
Pedestrian–car	Pedestrian	465.47	49.29	–	–	–	–
	Car	414.23	43.78	51.24	22	2.692	0.013
Pedestrian–BRT	Pedestrian	465.47	49.29	–	–	–	–
	BRT	351.13	79.17	114.34	22	4.247	0.0001
Bus–BRT	Bus	362.58	23.86	–	–	–	–
	BRT	351.13	79.17	11.45	22	0.480	0.636*
Car–bus	Car	414.23	43.78	–	–	–	–
	Bus	362.58	23.86	51.65	22	3.588	0.002
Car–BRT	Car	414.23	43.78	–	–	–	–
	BRT	351.13	79.17	63.1	22	2.416	0.024

*Mean difference not significant on 0.05 level.

Table 4. Group statistics of independent-sample *t*-test (n = 24)

	Period	Mean	Standard deviation	Mean difference	*df*	*t*	*p*-values
PM_{10}	Rush hour	413.84	71.15	–	–	–	–
	Non-rush hour	382.86	64.02	30.98	46	1.586	0.120*
$PM_{2.5}$	Rush hour	167.35	38.37	–	–	–	–
	Non-rush hour	148.43	38.20	18.92	46	1.712	0.094*
TSP	Rush hour	476.46	97.11	–	–	–	–
	Non-rush hour	420.31	70.34	56.15	46	2.294	0.026

*Mean difference not significant on 0.05 level.

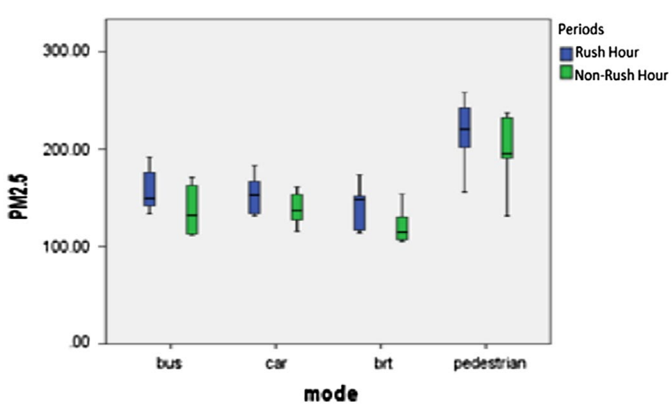

Figure 5. Box plot showing average $PM_{2.5}$ levels in various modes of transportation marked by period.

present study. Lower concentrations were experienced inside the car (153.61 ± 20.52 μg/m³ for morning and 138.63 ± 17.11 μg/m³ for afternoon) as shown in Figures 5 and 6. The average $PM_{2.5}$ concentrations inside BRT for both morning and afternoon periods are, respectively, 142.00 ± 22.77 and 121.03 ± 18.71 μg/m³. From Table 6, Student's *t*-test revealed statistically significant differences between pedestrian and other transport modes ($p < 0.05$).

Figure 6. Bar chart showing average concentrations of $PM_{2.5}$ in various modes of transportation marked by period.

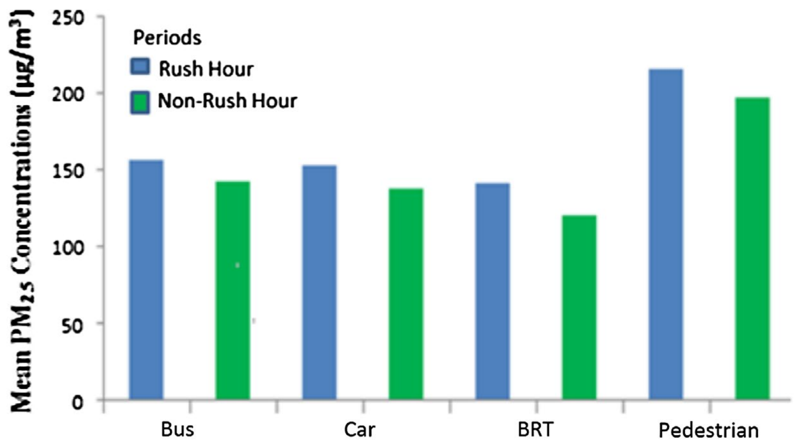

Table 5. Descriptive statistics of $PM_{2.5}$ concentration (µg/m³) in various modes of transportation

	Morning hours (am)						Afternoon hours (pm)					
Modes	**N**	**Mean**	**SD**	**CV (%)**	**Min**	**Max**	**N**	**Mean**	**SD**	**CV (%)**	**Min**	**Max**
Bus	200	157.02	22.24	14.16	133.59	191.71	205	142.57	27.14	19.04	111.28	176.00
Car	200	153.61	20.52	13.36	131.69	183.15	210	138.63	17.11	12.34	115.80	161.18
BRT	200	142.16	22.77	16.02	114.00	173.73	200	121.03	18.71	15.46	105.36	153.95
PDR	198	216.60	36.20	16.71	156.00	258.30	200	197.05	37.90	19.23	131.60	237.15

Notes: N: sample size; Mean: arithmetic mean; SD: standard deviation; CV: coefficient of variation; Max: maximum; Min: minimum.

Table 6. *t*-test for paired mean concentration of $PM_{2.5}$ between the modes of transportation (*n* = 12)

		Mean	Standard deviation	Mean difference	*df*	*t*	*p*-values
Pedestrian–bus	Pedestrian	206.83	36.78	–	–	–	–
	Bus	147.01	24.85	59.82	22	4.669	0.0001
Pedestrian–car	Pedestrian	206.83	36.78	–	–	–	–
	Car	146.12	19.64	60.71	22	5.044	0.0001
Pedestrian–BRT	Pedestrian	206.83	36.78	–	–	–	–
	BRT	131.60	22.73	75.23	22	6.028	0.0001
Bus–BRT	Bus	147.01	24.85	–	–	–	–
	BRT	131.60	22.73	15.41	22	1.585	0.127*
Car–bus	Car	146.12	19.64	–	–	–	–
	Bus	147.01	24.85	−0.89	22	−0.097	0.923*
Car–BRT	Car	146.12	19.64	–	–	–	–
	BRT	131.60	22.73	14.52	22	1.675	0.108*

*Mean difference not significant on 0.05 level.

4. Conclusion

The results and the analysis revealed that pedestrians were consistently exposed to the highest levels of particulate compared to commuters in any other mode of transportation. This fact was also buttressed by the analysis which revealed a statistically significant difference between pedestrians and commuters in each of the other modes of transportation, whereas in-vehicle exposure levels were statistically similar. The differences in the exposure levels inside the various modes of transportation for rush hours were found to be statistically similar to exposure levels for these modes measured during non-rush hour ($p > 0.05$).

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