Association between light absorption measurements of $PM_{2.5}$ and distance from heavy traffic roads in the Mexico City metropolitan area

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Abstract

Objective. To study the relationship between light absorption measurements of $PM_{2.5}$ at various distances from heavy traffic roads and diesel vehicle counts in Mexico City. **Materials and methods.** $PM_{2.5}$ samples were obtained from June 2003-June 2005 in three MCMA regions. Light absorption (b_{abs}) in a subset of $PM_{2.5}$ samples was determined. We evaluated the effect of distance and diesel vehicle counts to heavy traffic roads on $PM_{2.5}$ b_{abs} using generalized estimating equation models. **Results.** Median $PM_{2.5}$ b_{abs} measurements significantly decrease as distance from heavy traffic roads increases (p<0.002); levels decreased by 7% (CI95% 0.9-14) for each 100 additional meters from heavy traffic roads. Our model predicts that $PM_{2.5}$ b_{abs} measurements would increase by 20% (CI95% 3-38) as the hourly heavy diesel vehicle count increases by 150 per hour. **Conclusion.** $PM_{2.5}$ b_{abs} measurements are significantly associated with distance from motorways and traffic density and therefore can be used to assess human exposure to traffic-related emissions.

Key words: Carbon; vehicle emissions; roads; diesel exhaust; Mexico

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Asociación entre las mediciones de $PM_{2.5}$ por absorbancia y la distancia a vías de alto tráfico en la zona metropolitana de la Ciudad de México.
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Resumen

Objetivo. Evaluar la relación entre las mediciones de absorción de luz de las $PM_{2.5}$ a diferentes distancias de vías de tráfico y el aforo vehicular de diesel en la Ciudad de México. **Material y métodos.** Se realizaron mediciones de $PM_{2.5}$ y su análisis de b_{abs} en tres zonas de la Ciudad de México. Se usaron modelos GEE para evaluar el efecto de la distancia y el aforo vehicular de tráfico pesado sobre $PM_{2.5}$ b_{abs}. **Resultados.** Se observó una tendencia decreciente en la mediana de $PM_{2.5}$ b_{abs} conforme se incrementó la distancia a las avenidas de alto tráfico (p<0.002); los niveles decrecen en 7% (CI95% 0.9-14) por cada 100 metros de incremento. Las mediciones de $PM_{2.5}$ b_{abs} se incrementan en 20% (CI95% 3-38) cuando el aforo vehicular a diesel es mayor de 150 en una hora. **Conclusiones.** Las mediciones de $PM_{2.5}$ b_{abs} están significativamente asociadas con la distancia de avenidas con alto tránsito vehicular y con vehículos de diesel.

Palabras clave: carbono; emisiones vehiculares; avenidas; diesel; México

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Vehicular traffic is a major source of air pollution, in particular, nitrogen oxides (NOx) and particulate matter. Various studies have suggested that vehicular exhaust traffic is associated with respiratory health effects.[1-8] Many of these studies obtained measurements near roadways in the vicinity of homes or schools, especially those with heavy vehicular traffic.

Some studies have concurrently incorporated air contaminant measurements with vehicular traffic counts.[9,10] A study carried out by Brunekreef *et al*.[11] in the Netherlands reported that black smoke concentrations were correlated with the density of truck traffic and the percentage of time children were exposed downwind of the motorway. Black or elemental carbon (BC-EC) originates mostly from incomplete combustion of fossil fuels and is the main factor in particle light absorption or light transmission (b_{abs}) , expressed in inverse megameters [Mm-1]) in ambient air. This measurement could therefore be a good indicator of exposure to vehicular traffic.

About 85% of air pollution in the Mexico City Metropolitan Area (MCMA) comes from mobile sources (emission estimates). One of the main pollutants is $PM_{2.5}$, emission inventories in 2004 reported a $PM_{2.5}$ emission of 6 622 ton / year, of which 56.6% comes from mobile sources: the 83.2% from diesel fuels and 16.8% from gasoline vehicles.[12] The MCMA has carried out several studies to evaluate the composition of fine particles and their relationship to mobile sources.[13-18] High concentrations of EC were observed in areas with heavy diesel vehicle traffic.

The toxicity of the particles is a subject of interest to both toxicological and epidemiological investigations.[19] Elemental and organic carbon originating from vehicular exhaust have been recognized as likely being the most toxic components of the particles.[20-22] This paper describes the relationship among $PM_{2.5}$ b_{abs} (light absorption, b_{abs}), vehicle density, and the distance between the measurement location and roadways in different parts of the MCMA.

Materials and methods

Study design

As part of the larger cohort of school children in Mexico City previously evaluated,[23] we conducted local $PM_{2.5}$ in public schools in three areas of the southeastern part of the MCMA (Iztapalapa, Iztacalco and Nezahualcoyotl) from June 2003 to June 2005.

Location and population

The overall study population consisted of school children living in three Mexico City municipalities: Iztapalapa, Iztacalco and Netzahualcoyotl. These regions are characterized by high levels of traffic-related emissions. The present report includes data from a subsample of thirty-seven of the 107 schools (34.6%) attended by the children and were selected based on their distance to the closest roadways with heavy vehicular traffic (range: 24 - 800 m). The study area was divided into four zones for local $PM_{2.5}$ sampling: Iztapalapa-west, Iztapalapa-east, Iztacalco and Nezahualcoyotl (figure 1). Local $PM_{2.5}$ b_{abs} were obtained at 20 (54.1%) schools: five in Iztapalapa-west, six in Iztapalapa-east, four in Iztacalco and five in Nezahualcoyotl.

Air pollutant and traffic assessment exposure

$PM_{2.5}$ and b_{abs} measurements

Battery powered Minivol portable samplers with flow rates of 5 liters/min using 47 mm Teflon-membrane filters were used to monitor local daily 24-hour outdoor $PM_{2.5}$ concentrations. Measurements was conducted for two consecutive weeks in two zones (the first 11 schools) and then rotated to the other two zones (the additional nine schools). Minivols were located on school rooftops (3 m) and care was taken not to place monitors < 90 cm from the walls and windows or close to plants or trees. Each school was measured on average 14 times (range: 1-26) for two weeks during the period June 2003 to June 2005, for 20 months of monitoring.

$PM_{2.5}$ b_{abs} was analyzed in a subset of Teflon filters (n=207, 11.5%) using transmission densitometry at the Desert Research Institute (DRI), Nevada, USA. The transmission densitometry method measures optical density with an incandescent broadband lamp (400-650 nm, peaking at 575 nm) transmitted through a glass diffuser. Transmittance is measured before and after Teflon filter exposure, to determine particle b_{abs} and the difference in the logarithms of the transmitted light is proportional to the absorption of the particle deposit.[24] These results were used as a marker of diesel engine exhaust.[25] The transmission of "white" light through the Teflon-membrane filter was measured before and after aerosol sampling to determine particle b_{abs}.[26] Absorption measurement on the Teflon-membrane filters is highly correlated with elemental carbon (EC), measured with

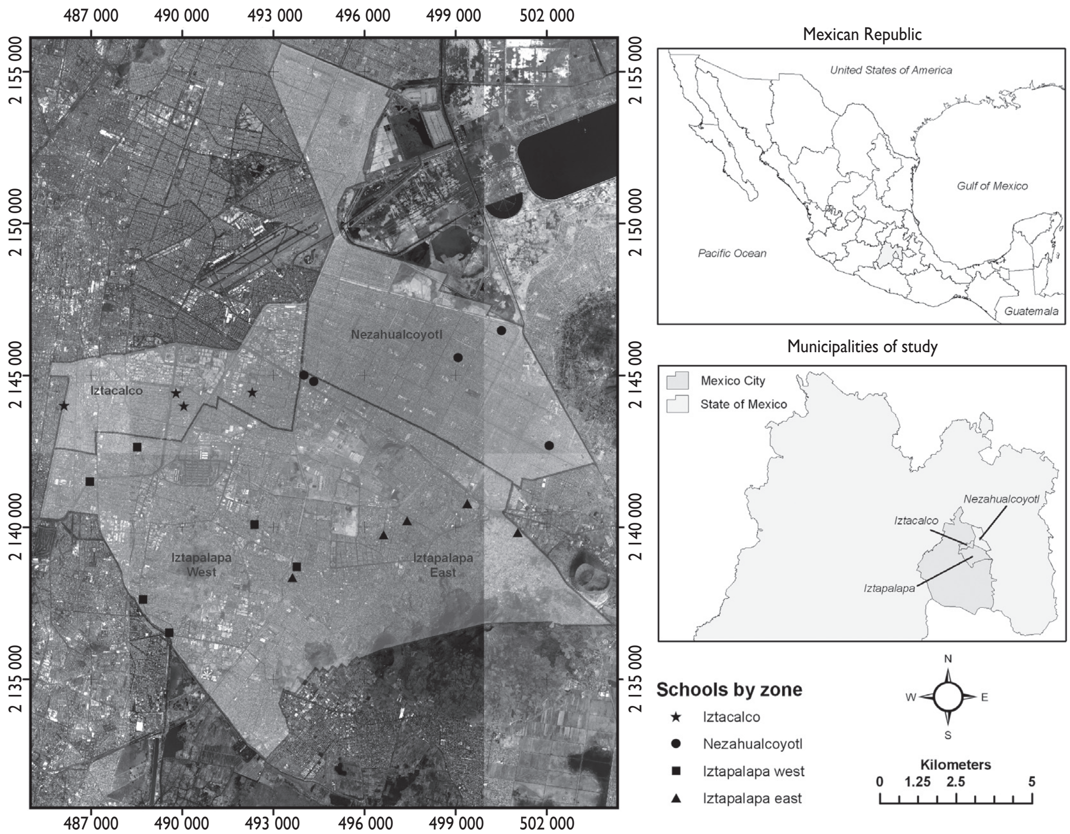

FIGURE 1. MAP OF THE STUDY AREA IN MEXICO CITY METROPOLITAN AREA (MCMA)

thermal/optical reflectance (TOR) analysis[27] $PM_{2.5}$ b_{abs} have been found to be highly correlated (r>0.86) with elemental carbon (EC), measured with thermal/optical reflectance analysis,[27-29] b_{abs} measurements in this study serve as EC surrogate.

NO_2 concentrations and meteorological data (temperature, humidity and wind velocity) were also obtained from the Mexico City government from four fixed-site central monitoring [Red Automática de Monitoreo Atmosférico (RAMA)] locations within the study area for the study period.

Traffic counts and distance from roadways

Traffic counts

Design of the traffic count study was based on the following criteria:

1. Geographic locations: traffic points sufficiently close to the selected roadways with heavy vehicular traffic (average 127 712 veh/hr).
2. Vehicle types: vehicle fleet was divided into the following five classifications:
   A= Private cars (gasoline);
   B= Small buses for public transportation (gasoline or natural gas)
   C= School buses, other buses, pick-up trucks (diesel)
   D= Light duty (diesel): 3.5 tons and double-axis pick-ups, small trucks and delivery vans
   E= High duty (diesel): two- and three-axle trucks, more than 3.5 tons pick-ups, auto-tanks, tractors, trailer-cabins with or without trailers, etc.
3. Traffic density: measured with pneumatic sensors every day for one week. The week selected was considered representative of traffic in that area. The average density of motor vehicles by type of vehicle, time of day, and day of the week was calculated for the study period.

A total of 51 roadway intersections distributed across the four study zones were measured. Nineteen out of the 51 intersections correspond to school locations selected for the b_{abs} analysis.

Distance measurement

The distances between each selected school and the nearest to the main vehicular traffic roadways (mean: 224 m, range: 24 – 838 m) were measured by means of a geographic information system (GIS). Schools were represented by points (sampling locations) and roadways by lines in the GIS. Distances between points and lines were calculated using NEAR command, in ARCGIS.

Statistical analysis

We conducted a descriptive analysis for $PM_{2.5}$ b_{abs} measurements by study zone, vehicular count and distance. We used Kruskal Wallis nonparametric test and a test for trend across ordered groups to evaluate the association between $PM_{2.5}$ b_{abs} measurements and distance of the school to nearest major roadway. We also used generalized estimating equation models (GEE) to evaluate the association between distance to heavy traffic roads and the diesel vehicle counts on $PM_{2.5}$ b_{abs} measurement (n=200). The predictor variables included in these models were distance between each selected school and the nearest heavy vehicular traffic roadway (m) and vehicle type C, D or E (1= >150 vehicles 0= ≤ 150 vehicles). The $PM_{2.5}$ b_{abs} (Mm^{-1}) were log-transformed to achieve normality. The model was adjusted for the following variables: local $PM_{2.5}$, average ambient NO_2, minimum temperature, study zone, wind velocity, average relative humidity on the day that samples were taken and time trend. Monitoring data were analyzed using the statistical software package STATA (version 9.2).

Results

The largest proportion of vehicles (76%) consisted of private cars (transport type A); small buses for public transportation (transport type B) represented 15.3% of the vehicles. Transport types C, D and E—predominantly diesel vehicles—represented 8.7% of the hourly 24-h average (data not shown). On average, the distance from the school monitored to the closest roadway with heavy vehicular traffic was 175 m (SD = 147) (table I).

$PM_{2.5}$ b_{abs} measurements were slightly higher (115.3 Mm-1) in the area of Iztapalapa east (table II and figure 2), which is the same area that presented a higher density of diesel vehicles (ratio gasoline / diesel=5.6). The highest $PM_{2.5}$ b_{abs} were within the first 50 meters of the roadway with heavy vehicular traffic. The median of $PM_{2.5}$ b_{abs} measurements was different between distance groups (p*= 0.06) and decreased significantly (test or trend p**= 0.02) with increased distance from the roadways from 50 to >250 (table III). Our multivariate model confirm the role of distance and the number vehicular using diesel as predictor of EC levels often adjusting for local $PM_{2.5}$, average ambient NO_2, minimum temperature, study zone, wind velocity, average relative humidity on the day the samples were taken and time trend (table IV).

Discussion

Our results suggest that, on average, the highest $PM_{2.5}$ b_{abs} were within the first 50 meters of roadways with heavy vehicular traffic and that exposure to $PM_{2.5}$ b_{abs} decreases (p<0.002) at distances greater than 50 meters. The results from the multivariate regression analysis suggest that $PM_{2.5}$ b_{abs} measurements would increase by 20% (CI95% 3-38) when the hourly traffic count for

Table I

Characteristics of the study locations. Mexico City metropolitan area, 2003-2005

Traffic count (vehicles/day) and distance (m)	*Mean*	*S.D.*	*Median*	*Interquartile range**
A= automobiles traffic density	2396	1370	2094	1721
B= public transport of passengers traffic density	372	283	471	598
C= private transport traffic density	34	45	7	61
D= Light duty traffic density	105	87	62	130
E= High duty traffic density	105	105	72	177
Total C, D and E traffic density	244	201	150	375
Distance between each school and the nearest heavy vehicular traffic avenue (m)	175	147	143	183

* IQR: (Q25-Q75)

Table II

$PM_{2.5}$ B_{abs} DISTRIBUTION MEASUREMENTS (MM-1). MEXICO CITY METROPOLITAN AREA, 2003-2005

Study zones	*n**	*Mean*	*Median*	*S.D.*	*Interquartile Range*
Iztacalco	57	107.5	97.0	56.0	94.1
Nezahualcoyotl	52	93.1	92.9	43.3	55.2
Iztapalapa West	46	98.1	81.3	54.8	99.8
Iztapalapa East	52	115.3	97.7	57.7	110.6
Total	207	103.8	92.4	53.5	91.7

* # observations

Table III

CONCENTRATION OF MEDIANS $PM_{2.5}$ B_{abs} MEASUREMENTS BY DISTANCE GROUPS. MEXICO CITY METROPOLITAN AREA, 2003-2005

Number of observations	*Distance from roadway (m)*	*Median (Mm-1)*[§]	*(p25, p75)*
54	≤ 50	112.9	(70.5, 159.8)
68	>50 ≤ 150	93.9	(61.9, 152.7)
37	>150 ≤ 250	72.5	(46.1, 119.0)
48	>250	77.4	(52.6, 157.2)

p25: 25th percentile. p75: 75th percentile

§ Kruskal-Wallis Test (p=0.06) and test for trend across ordered groups (p=0.02)

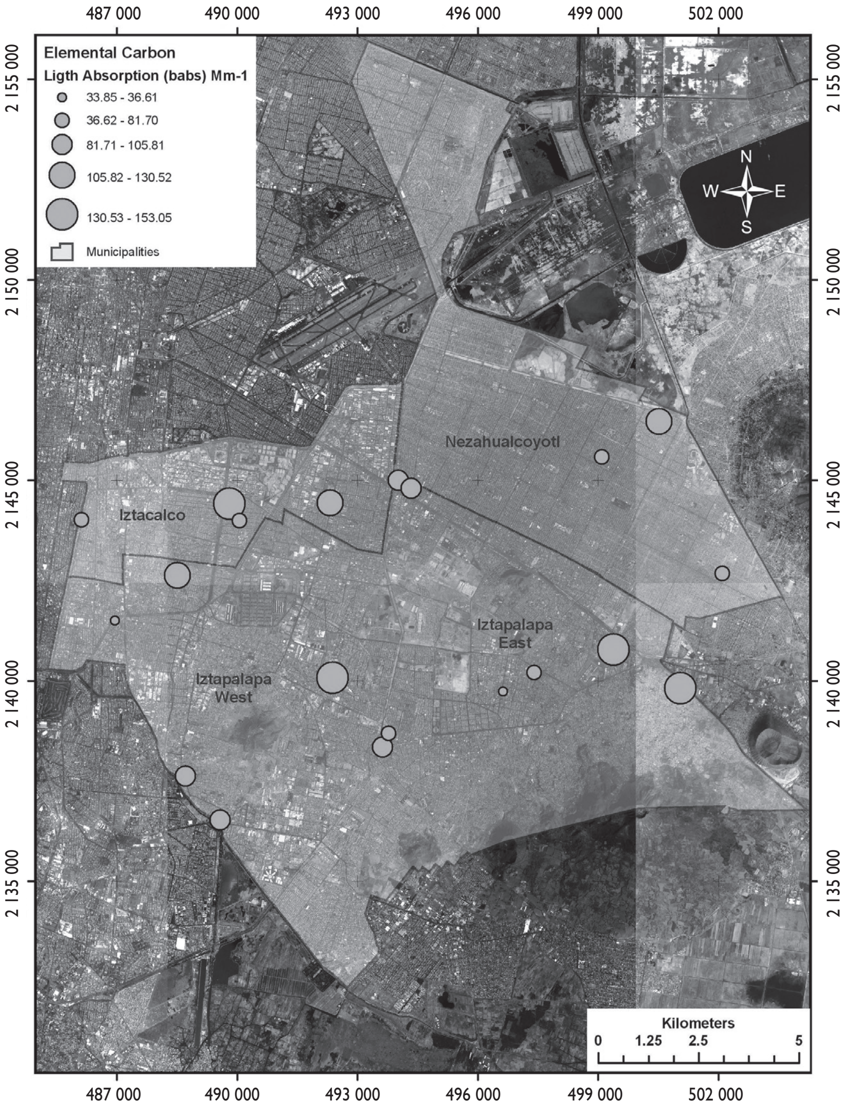

FIGURE 2. SPATIAL DISTRIBUTION OF MONITORING SITES AND CONCENTRATION GRADIENTS OF LIGHT ABSORPTION (B_{abs})

Table IV
Predictors of $PM_{2.5}$ b_{abs} measurements in Mexico City metropolitan area, 2003-2005

Variables	β*	*CI95%*	*P-value*
Distance	-0.07	-0.135 – -0.008	0.028
Vehicle type C, D y E	0.20	0.031 – 0.370	0.021
Local $PM_{2.5}$	0.02	0.008 – 0.024	0.000

* Predictor (95%CI). Multivariate model was adjusted by local $PM_{2.5}$, average ambient NO_2, minimum temperature, wind velocity, average relative humidity on the day the samples were taken, study zone and time trend. Our fitted model was $\text{Log } b_{abs} = 0.372 - 0.07X_1 + 0.20X_2 + 0.02X_3 + 14.9X_4 - 0.03X_5 + 0.29X_6 + 0.01X_7 - 0.09X_8 - 0.22X_9 - 0.28X_{10} + 0.0002X_{11}$ where X_1= distance between each selected school and the nearest heavy vehicular traffic avenue (each 100 m), X_2= Vehicle type C, D y E (1= >150 vehicles 0= ≤ 150 vehicles), X_3= Local $PM_{2.5}$, on the sampling day X_4= Mean average ambient NO_2 on the sampling day, X_5= Mean minimum of Temperature on the sampling day, X_6= Mean minimum of Wind speed on the sampling day, X_7= Mean average of Humidity on the sampling day, X_8= Study zone 1 (1 or 0), X_9= Study zone 2 (1 or 0), X_{10}= Study zone 3 (1 or 0) and X_{11}= Date of sampling (Time trend)

type C, D and E vehicles increases by 150 vehicles per hour In addition, for each additional 100 meters from heavy traffic roads with high a percentage (>10%) of diesel vehicles, $PM_{2.5}$ b_{abs} measurements would decrease by 7% (CI95% 0.9-14.0).

These results suggest that distance from heavy traffic roads and traffic intensity can be used as a surrogate for exposure to traffic-related EC in epidemiological studies, especially where diesel vehicles are present.

In our study, the $PM_{2.5}$ b_{abs} measurements ranged from 14.9 to 222.4 Mm-1. These measurements were conducted in a very densely populated area (Iztapalapa east) and are higher than that reported by Vega *et al*.,[30] however, Chow *et al*.[17] have reported spatial variation of PM_{10} b_{abs} among areas in the MCMA, with the highest concentrations being in the eastern area, corresponding to our study area.

Compared to concentrations reported in other cities, our b_{abs} measurements are four to five times higher,[31-33] suggesting poor quality diesel vehicles are driven and a significant fleet of vehicles emit diesel, producing a large amount of fine and ultrafine particles in the MCMA. Even though different studies used different methods for measuring carbon, high correlations have been observed among the different methods.[28,34,35]

Our results are concordant with other studies that reported that levels of EC emitted by vehicles increase proportionally to the distance from avenues or mobile sources of emissions.[9,15,36-38] Consequences for public health are likely to be large given the adverse health effects observed in people living near roads with high traffic density.[5,6,8,11,33,39,40]

This study suggests that $PM_{2.5}$ b_{abs} measurements from diesel vehicles are significantly associated with distance to the motorway and traffic density. These variables can therefore be used to assess exposure to traffic-related EC in subjects living near motorways.

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The ethics committee of the National Institute of Public Health approved the research protocol which are the data analyzed in this article.

Declaration of conflict of interests. The authors declare that they have no conflict of interests.

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