

Seasonal variation of atmospheric lead levels in three sites in Mexico City

IRMA ROSAS, RAUL BELMONT and ERNESTO JAUREGUI

Centro de Ciencias de la Atmósfera, UNAM, Circuito Exterior, CU, 04510 México D. F., México

(Manuscript received Feb. 2, 1995; accepted in final form March 13, 1995)

RESUMEN

Durante 1991 se evaluaron en tres sitios (industrial, comercial y residencial), las concentraciones de plomo atmosférico asociado a partículas menores de $10\ \mu\text{m}$, con el objeto de establecer los cambios en los niveles de este contaminante. Además, se trató de establecer la posible relación de este contaminante con los niveles de plomo en sangre citados para niños y mujeres que viven en los alrededores de los sitios de muestreo.

Se observó un marcado gradiente del plomo atmosférico de Norte a Sur, con valores más altos y variables en la zona norte, en donde se localiza la zona industrial.

Las concentraciones de plomo y su correspondiente variabilidad decrecieron gradualmente (de 1.2 a $0.5\ \mu\text{g m}^{-3}$) hacia la zona sur. Además, estos valores son significativamente más altos durante la época de secas que la de lluvias, debido al efecto marcado de lavado atmosférico. Sin embargo, los promedios trimestrales registrados durante el periodo de muestreo no sobrepasaron el estándar internacional de $1.5\ \mu\text{g m}^{-3}$.

Las concentraciones de plomo y los correspondientes valores de PM_{10} mostraron una correlación significativa. Esto indica que el plomo está asociado a la fracción fina de las aeropartículas, lo que determina una alta probabilidad de depósito en el tracto respiratorio.

Los resultados obtenidos en el presente estudio al ser comparados con los de 1990, muestran una reducción substancial. Esto puede ser explicado por la introducción de una gasolina de mejor calidad. A pesar de esto, más del 30% de la población evaluada presentó niveles de plomo, mayores de $10\ \mu\text{g dL}^{-1}$, en sangre.

ABSTRACT

Atmospheric lead concentrations associated to particles smaller than $10\ \mu\text{m}$ were measured in Mexico City, to establish changes of levels of this pollutant in three sites (industrial, commercial and residential) for 1990-1991. Moreover, an attempt was made to establish a possible link between this airborne pollutant and blood lead levels reported in children and women living near the sampling sites.

A marked gradient in atmospheric lead from North to South is observed with higher and more variable mean lead values in the northern site where industry is located.

Lead concentrations and their corresponding variability gradually decrease (from about 1.2 to $0.5\ \mu\text{g m}^{-3}$) toward the southern suburbs. Moreover, these values are significantly higher during the dry season than in the wet season when a marked washout effect is observed. However, the quarterly averages recorded during the sampling time do not exceed the international standard ($1.5\ \mu\text{g m}^{-3}$). Lead concentrations and corresponding PM_{10} values showed a significant correlation. This result shows that lead is associated to the fine fraction of airborne particles, with high proportion of them deposited in the respiratory tract.

A substantial abatement in levels of atmospheric lead is observed in 1991 with respect to the previous year. This may be explained by the introduction of improved quality gasoline in the capital city. In spite of this measure more than 30% of the evaluated population in 1991 presented blood-lead levels $> 10\ \mu\text{g dL}^{-1}$.

1. Introduction

High concentrations of lead have been reported in urban atmospheres in mid-latitude cities (Albert and Badillo, 1991; Cicero-Fernández, 1991; Kretzschmar, 1992; Romieu *et al.*, 1992). Through its use in paint and petrol, lead becomes one of the most widely dispersed toxins of the XXth century. Important to the human environment are emissions of lead to the atmosphere (Shy, 1990).

Within urban areas most of the lead compounds found in the atmosphere result from leaded gasoline combustion. During the lifetime of motor vehicles, approximately 35% of the lead contained in burned gasoline are emitted as small particles ($<0.25 \mu\text{m}$) and approximately 40% is emitted as larger particles ($>10 \mu\text{m}$) (Ter Haar *et al.*, 1972). This condition contributes not only to lead being consumed through inhalation, but also to an increase of lead being introduced in the urban environment. Thus, ingestion of deposited lead in dust, soil, food and water can also contribute to 50% of the total intake (Duggan *et al.*, 1985).

In mid-latitude cities it has been reported that respiratory deposition in the lungs of ambient airborne lead is approximately 30-50%, depending upon particle size and ventilation rate; in addition, more than 90% of the deposited lead is absorbed into the blood stream (Morrow *et al.*, 1980; Gross, 1981; Chamberlain *et al.*, 1983).

Preliminary studies of atmospheric lead in Mexico City date from the early 1970's. (Bravo *et al.*, 1970; Espinoza *et al.*, 1978; Salazar *et al.*, 1981; Falcón *et al.*, 1986). Although sampling was made for short periods of time, results of these studies were coincident with those obtained by the official network established by SEDUE (Ministry of Urban Development and Ecology), the official air pollution control agency. Also all of them, confirmed the presence of significant levels of airborne lead, showing a potential health risk for the population of Mexico City. Using lead concentration data from a network of about 14 monitoring stations sets up by SEDUE (Jáuregui and Sánchez, 1987) analyzing lead level in Mexico City from years 1978 to 1985 noted an increasing trend for the period. Also was observed a seasonal variation with low values during the rainy season and higher values in the northern (industrial) part of the city, decreasing toward the southern suburbs.

Reduction in the lead concentration in gasoline started in Mexico in 1980. By 1992 tetraethyl lead concentrations in NOVA gasoline decreased from 3.5 (in 1980) to 0.4 ml per gallon in 1992. If official numbers are correct, the level of lead in Mexico City is now similarly to that used in gasolines in the European Economic Community (SEDESOL-INE, 1992). Since September 1990 unleaded gasoline (Magna-Sin) has been used in recent models with catalytic converters; however, it only represented 8% of the consumed fuel (SEDESOL-INE, 1991-1992).

The objective of this study is to estimate the recent status of atmospheric lead levels in the capital city and thus determine whether the measures taken by the city authorities (i.e., improvement of the quality of gasoline, day-without-a-car, mandatory vehicle emission smog checks twice a year, compulsory tune-up, extension of the underground transport system, etc.) have resulted in a reduction of levels in this toxic pollutant. Effects of some meteorological factors on concentration of lead in the urban air particles are also examined. Finally, the possible impact of atmospheric lead on the exposed population was explored.

2. Climate and sampling sites

Mexico City is one of the largest (about 1200 Km^2) urban areas in the tropical (lat. 20°N) environment. Located in an elevated basin (2250 m) in central Mexico (Fig. 1), the climate

of the capital of Mexico is of a tropical character tempered by altitude. A well marked rainy season caused by the arrival of the moist trade winds from the Gulf of Mexico and the Pacific predominates between May - October. During the cool season the trades give way to the dry continental Westerlies that occasionally are associated with cold polar out-breaks that sweep away (for a few hours) the air pollution from the capital city.

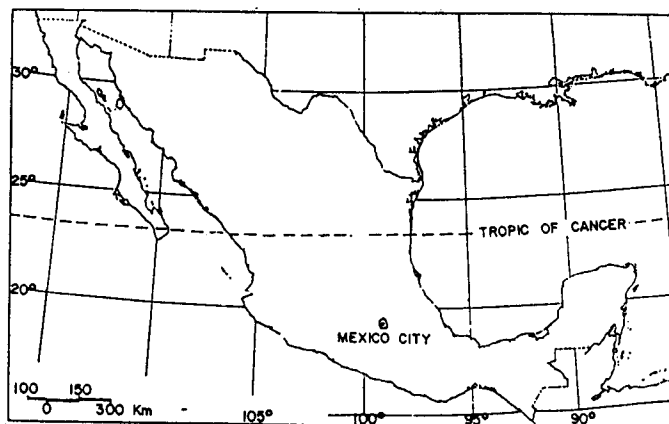
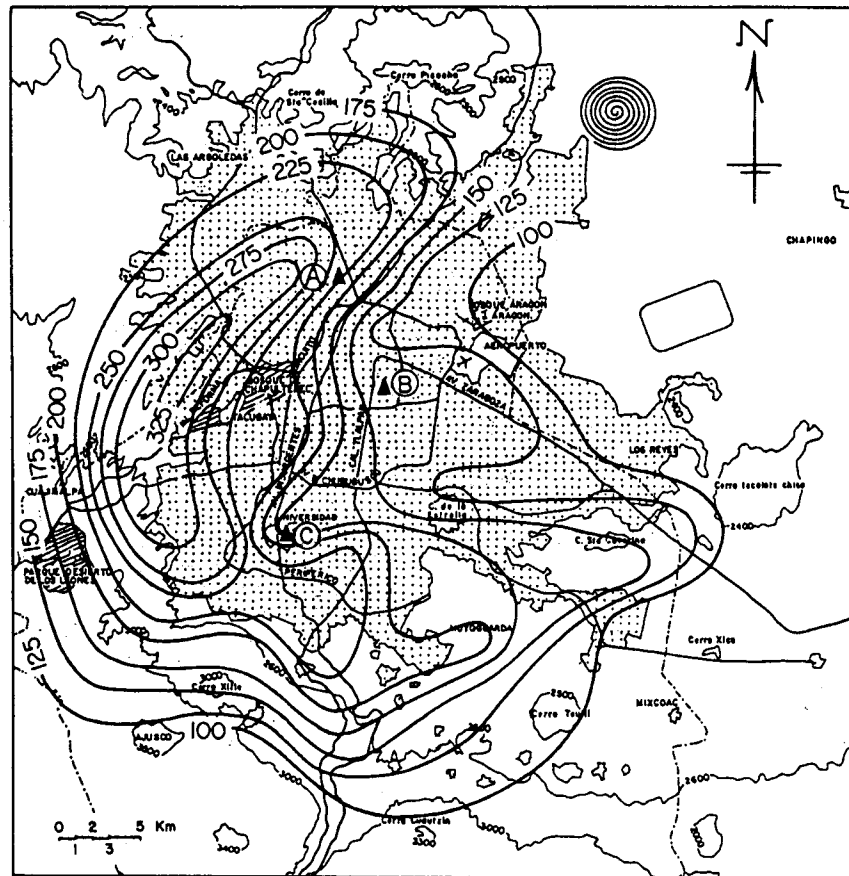


Fig. 1. Location of the stations and rainfall distribution (mm) for July 1991.

The following localities were selected for this study (Fig. 1): Coyoacan District (C), a residential area situated in the southern part of the city, some 20 Km from downtown, with a low urbanization index (UI) of 0.15 (referred to the percentage of the built-up area). Cuauhtemoc District (B), a commercial-urban area is located in downtown, with a UI of 1.0 (Rapoport *et al.*, 1983); and finally, a northern location in the heavily industrial District of Vallejo (A) with a UI of 0.65.

3. Methods

3.1 Gravimetric Concentrations of Airborne Particles

Particle mass of smaller than 10 μm (PM_{10}) concentration levels were routinely monitored for four consecutive days per week, during one year in 1991, at two sampling sites in Mexico City, PM_{10} was sampled using the model Sierra Andersen/GMW Model 1200 VFC HVPM10. The sampler flow rate was kept constant at 1.13 $\text{m}^3 \text{min}^{-1}$ using G 313 flow control modules. For sample collection, glass fiber filters were used.

Atmospheric PM_{10} mass concentrations were obtained gravimetrically by weighting the filter, before and after sample collection. A analytical milligram balance with a 0.1 mg sensitivity (Sartorius model A 200S) was employed for this purpose. Unexposed and collected filters were equilibrated at $22^\circ\text{C} \pm 3^\circ\text{C}$, and collected filters were at $50 \pm 3\%$ relative humidity for at least 24 hours before weighting the filter.

3.2 Lead in air filters

Ten square inches were taken from the air filter and digested with 15 ml of 3M HNO_3 and 1 ml of H_2O_2 in a glass beaker covered with a watch glass and boiled gently on a hotplate for 30 min. The sample solution was transferred to a 100-ml volumetric flask with the rinsing water from both beaker and watch glass also added, and made up to volume with deionized water.

For a quality control eighteen treated blank filters were spiked with six different concentrations of lead that covered the expected levels in the exposure filters. These filters were treated as described above for the samples. The solutions were analyzed for lead by flame atomic absorption spectrophotometry using a Perkin Elmer 460, with deuterium background correction.

The results of the quality control samples were evaluated using linear regression analysis. For acceptance the empirical line had to fall inside the acceptance of 95% (UNEP/WHO, 1986; Friberg, 1988).

3.3 Meteorological data

Temperature, relative humidity, wind speed and rainfall data were obtained from meteorological stations distant about 2 to 7 km from the sampling sites. The specific humidity was also calculated ($q = 0.622 e/p$) where: e: ambient vapor pressure (mb), p: barometric pressure (mb).

3.4 Statistical methods

Since the data displayed a normal frequency distribution, analysis of variance (ANOVA) was applied to the data to compare the airborne lead concentrations at different seasons of the year

(Student's t test) and sampling sites (Fisher's test). Pearson's correlation coefficients were calculated to test for correlation between airborne lead concentrations and different environmental factors (Sokal and Rohlf 1969, Hoaglin *et al.*, 1991).

4. Results

The seasonal and spatial distribution of airborne lead during an annual period is presented in Figures 2-3. Figure 2 shows box plot diagrams for the three sites illustrating the extreme and median values for the wet (May-Oct) and dry season. It is readily seen that lead concentrations are significantly higher during the dry period than during the rainy season, when a reduction of about 30-40% is observed, suggesting a washout effect. Lead levels are considerably higher (and more variable) in the northern location with a median of $1.18 \mu\text{g m}^{-3}$, where the main industrial sources are situated, and decrease gradually toward the central and southern sites with median values of $0.70 \mu\text{g m}^{-3}$ and $0.52 \mu\text{g m}^{-3}$ respectively.

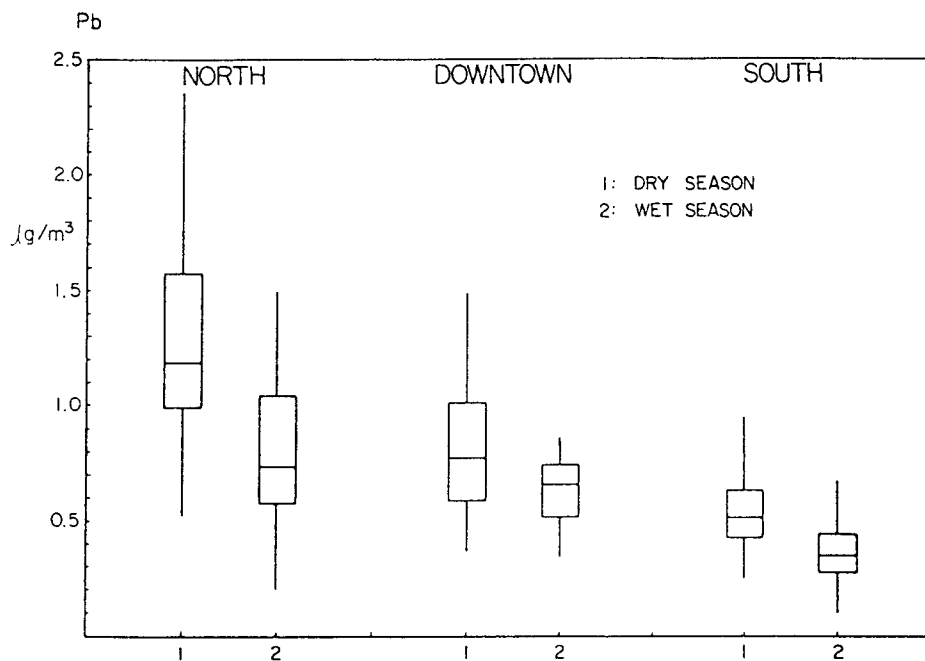


Fig. 2. Schematic boxplot for seasonal and spatial distribution of airborne lead concentrations.

The seasonal distributions of daily rainfall, PM_{10} and lead for the three sites are shown in Figure 3. While the PM_{10} and lead levels seem directly related, the lead concentrations appear to be inversely linked to rainfall occurrence. Other meteorological variables that could effect lead concentrations (i.e., temperature, wind speed), were tested for significance. The results are shown in Table I. As would be expected, a good correlation was obtained between PM_{10} and airborne lead, with values ranging from 0.57 in the southern site to 0.41 in downtown, both values with $p < 0.05$ level of significance.

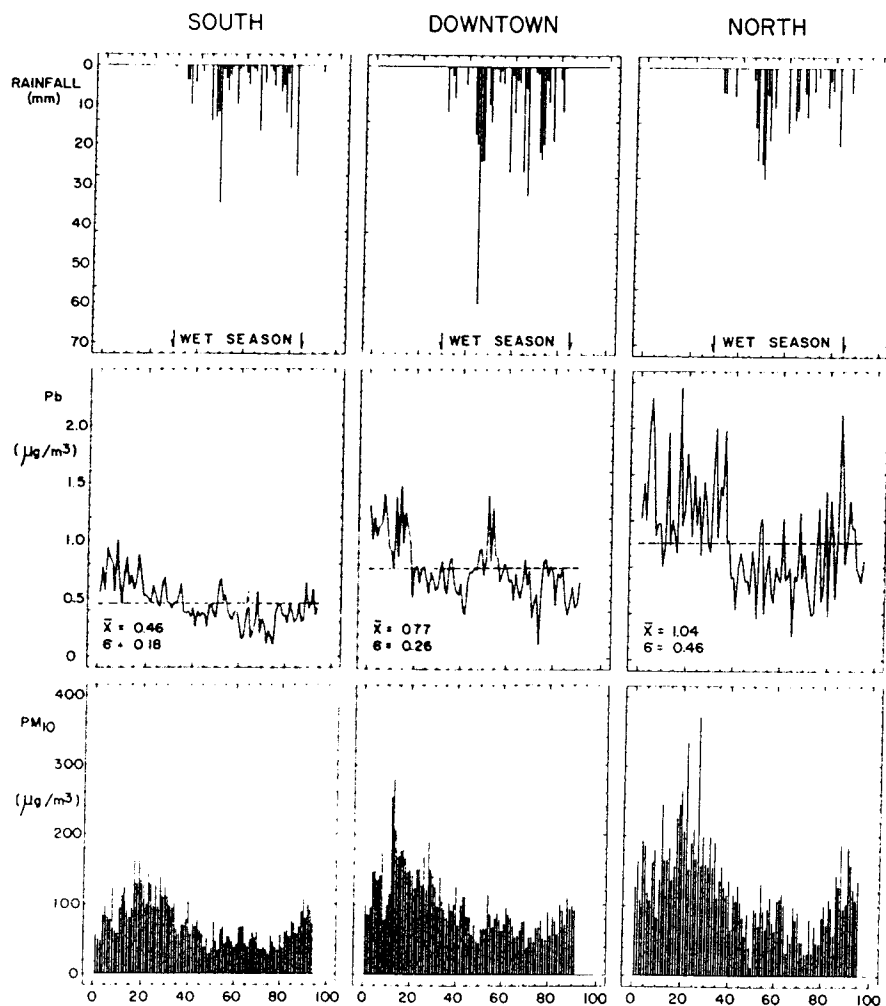


Fig. 3. Seasonal distribution of rainfall, airborne lead and PM_{10} at the three sampling sites.

The correlation of lead levels with rainfall showed a negative sign. The values were low but significant at $p < 0.05$ in downtown and in the north. A better correlation of lead concentrations was obtained with a humidity parameter (specific humidity) that is linked to rainfall, as shown in Table I. Also, as would be expected, airborne lead showed an inverse correlation with minimum temperature. This suggests that lead concentrations increase during more stable (i.e., surface inversion) surface layer conditions. Other meteorological parameters like wind speed did not show significant correlation with atmospheric lead.

In relation with air quality standards, airborne lead concentrations expressed as quarterly averages did not exceed the local standard of $1.5 \mu\text{g m}^{-3}$. However, PM_{10} values were higher than the California 24 hour standard of $150 \mu\text{g m}^{-3}$ (Solomon *et al.*, 1989) in 16% and 36% of the samples at locations B and A, respectively (Fig. 1). Also in all of them, the annual arithmetic means surpassed the US PM_{10} standard (Table II). The monthly average concentrations of

airborne lead obtained from the official air quality network during 1990-1991 and those that resulted from this study at the same sampling site (downtown) or very close to it, are shown in Figure 4. In general a significant reduction of lead levels seems to have occurred from 1990 to 1991, except in the north (industrial area). Blood-lead levels in different populations of both women and children living in the vicinity of the sampling sites of the present study are shown in Table III. High concentrations were obtained from people residents of either northern or downtown area. Also the lead-blood levels recorded during 1986 appear to be higher than those obtained after 1990. Still the proportion of subjects that presented levels $> 10.0 \mu\text{g dL}^{-1}$ is higher than 30%.

TABLE I. PEARSON'S CORRELATION COEFFICIENT VALUES BETWEEN AIRBORNE LEAD AND SOME ENVIRONMENTAL FACTORS.

Dependent variable: Airborne lead ($\mu\text{g}/\text{m}^3$)	Sampling sites		
	South N=94	Downtown N=90	North N=92
Independent variables:			
$T_{\text{min.}} \text{ } ^\circ\text{C}$	-0.30*	-0.32*	-0.27*
PM_{10} ($\mu\text{g}/\text{m}^3$)	0.57*	0.41*	0.52*
Rainfall (mm/day)	-0.18	-0.21*	-0.25*
$T_{\text{max}} \text{ } (^\circ\text{C})$	0.05	0.04	0.03
Wind speed (m/s)	0.20*	-0.03	-0.02
Specific humidity (g/kg)	-0.21*	-0.32*	-0.39*

* $p < 0.05$

TABLE II. SUMMARY OF AIRBORNE LEAD AND PM_{10} CONCENTRATIONS IN THE NORTH (A), DOWNTOWN (B) AND SOUTH (C) AREAS IN MEXICO CITY

PARAMETER	CONCENTRATION $\mu\text{g}/\text{m}^3$			STANDARDS US/MEXICO $\mu\text{g}/\text{m}^3$	% EXCEEDANCE		
	A	B	C		A	B	C
PM_{10} : Max. 24 hour	372.5	281.9	163.7	150	36	16	2
AAM	125.8	104.6	75.7	50	119	92	39
AGM	109.8	96.1	69.4	+			
Pb: Max. QA	1.38	1.02	0.67	1.5	0	0	0
AAM	1.10	0.77	0.45	0.5-1.0*			

AAM : Annual Arithmetic Mean

AGM : Annual Geometric Mean

QA : Quarterly average

*: WHO

+: NO Standard established

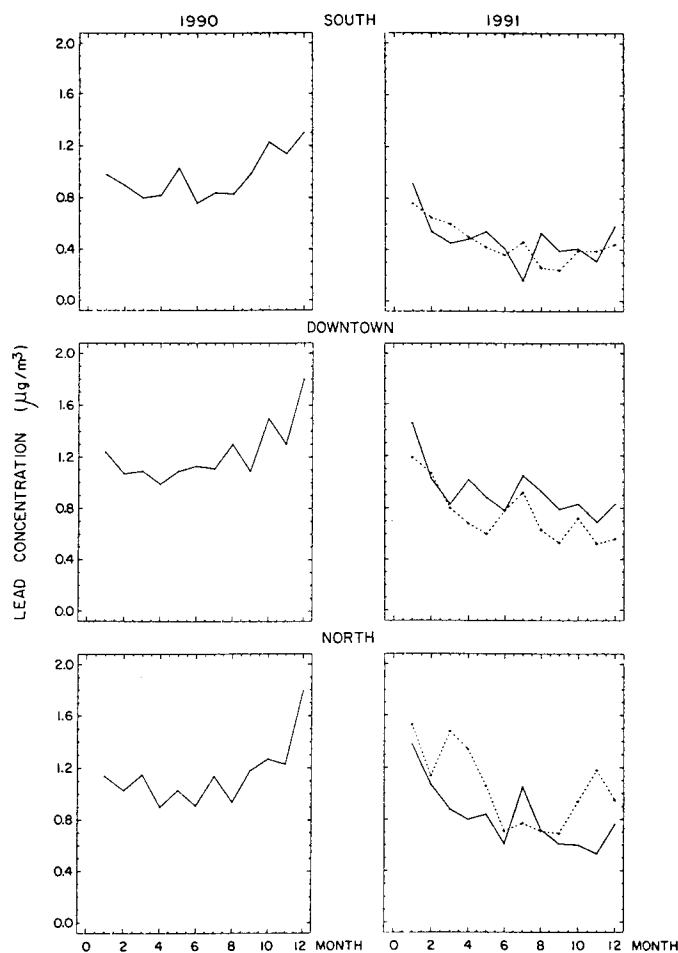


Fig. 4. Comparison between airborne lead monthly average concentrations from sedesol 1990-1991 (—) and those from this study (---) 1991.

Table III. Blood levels in both children and women living in different areas of Mexico City

Site	Sample size	Lead-blood ($\mu\text{g dL}^{-1}$) average	SD	% >10 $\mu\text{g dL}^{-1}$	References
Children					
South	102	9.5	6.0	37.3	Romieu <i>et al.</i> , 1993
Downtown	54	15.3	6.4	70.0	Calderón <i>et al.</i> , 1994
North	101	10.4	5.5	49.5	Romieu <i>et al.</i> , 1993
Women					
South	58	18.9	6.0	----	Lara <i>et al.</i> , 1989*
	102	9.3	6.1	37.3	Romieu <i>et al.</i> , 1993
Downtown	50	19.4	9.0	----	Lara <i>et al.</i> , 1989*
North	50	14.7	4.0	----	Lara <i>et al.</i> , 1989*
	101	10.3	6.25	46.5	Romieu <i>et al.</i> , 1993

* Average, 16.6 % of the women > 25 $\mu\text{g dL}^{-1}$

5. Discussion

Despite active research, the contribution of atmospheric lead to the complete body burden of lead in the general community remains unclear. Some studies suggest that the most body lead is derived from gasoline lead exhaust (USEPA, 1982; USEPA, 1986; Arnetz and Nicolich, 1990) while others indicate considerable weaker associations (Chamberlain, 1983; Vahter *et al.*, 1991). However, an international strategic plan for the reduction of lead poisoning, principally to protect children at risk is now under way (Thornton *et al.*, 1990; Goyer, 1993).

In Mexico City, the reduction over the past several years of tetraethyl lead in gasoline from 3 ml gal⁻¹ to 1 ml gal⁻¹ and the introduction of unleaded gasoline (PICA, 1990), has brought about a decrease in atmospheric lead which has reached in 1991 the maximum quarterly averages (QA) of 0.67 and 1.02 $\mu\text{g m}^{-3}$ in locations C and B respectively. These areas are characterized by heavy and continuous traffic, implying that the local motor vehicle emissions are the main atmospheric lead sources. However, quarterly average did not exceed either the local or US standards. When comparison is made between atmospheric lead levels observed by SEDESOL during 1990 and those obtained in this study (1991) a marked decrease of about 40% is evident. However, with respect to the northern site, the reduction was only 9%. This suggests that the predominant source of airborne lead in this area is mainly of industrial origin.

On the other hand, if a comparison is made between the maximum quarterly averages obtained in this study (from 0.67 to 1.38 $\mu\text{g m}^{-3}$), with those in the EPA graph for estimate of gasoline lead emission and outdoor lead concentrations for 1975-1986 (USEPA, 1986), it is clear that the consumption of lead gasoline is still high ($> 100 \times 10^3$ ton year⁻¹).

A typical urban atmosphere has a lead concentration of 0.5 to 1.0 $\mu\text{g}/\text{m}^3$ with higher values during the winter months due to an increased combustion of fossil fuels and to prevailing low air temperature near the surface (Harrison and Williams, 1982). During the dry season, high concentrations of lead and PM₁₀ are observed, in sites A and B as a result of local sources plus the contribution from the industrial area at the north. These high levels are observed when low temperatures (- 2 to 12°C) combine with frequent surface inversions that further restrict turbulent mixing in this period (Jáuregui, 1986, PICA, 1990).

During the wet season two processes take place: first the washout process removes airborne lead and particles; another process resuspends those dust particles containing lead, by rain-splash. The last mechanism and the transport of lead from the industrial area by the prevailing NE wind, could explain the high values observed during this season; the generally decreasing values observed at the end of the wet season are likely to be the result of rainwater runoff that removes the lead from the streets and vegetated surfaces (Khanderkar *et al.*, 1980).

The good correlation found between PM₁₀ and airborne lead has also been reported by Robinson and Ludwig (1967) and Harrison and Williams (1982). These authors suggest that airborne lead is associated basically with the fine particle fraction, since this metal is a component of small particles that are produced by high temperature combustion processes of the tetraethyl lead in automobile engines. 50% of inhaled lead from small particles deposited in the respiratory tract, has been reported to be absorbed (Vahter *et al.*, 1991), this could explain the good correlation found between vehicular traffic and blood lead levels in children living in the capital city (Romieu *et al.*, 1992). On the other hand the similar spatial distribution of both airborne lead levels and blood lead concentrations, suggests that the Mexico city population be exposed to atmospheric lead particles and probably not only via direct inhalation, but through ingestion of deposited particles as well, especially among young children (Calderón, 1994).

Notwithstanding that a decrease of blood-lead levels has been observed, in recent times a high percentage of the Mexico City population shows blood-lead levels greater than 10 $\mu\text{g dL}^{-1}$. This

concentrations could be associated to high soil and house dust lead levels (Calderón, 1994) as well as to the widespread custom of preparing food in lead glazed ceramics (Hernández-Avila *et al.*, 1991).

Efforts by city authorities to reduce such toxic air pollutants as lead has met with mixed success. While the introduction of a new low lead-content gasoline has abated atmospheric lead levels in the capital city, it seems that this measure has given rise to higher concentrations of ozone precursors (Bravo *et al.*, 1988). More research needs to be done in order to improve our knowledge of atmospheric lead in México City's environment and its impact on health.

6. Acknowledgements

This research was partially supported by the Instituto Mexicano del Petróleo and the British Council. We thank Jorge Estrada, Alma Yela, Ma. Carmen Torres B., Carmen González-Macías and Jorge Escalante for their cooperation and technical assistance.

REFERENCES

- Albert, L. and F. Badillo, 1991. Environmental lead in Mexico. *Reviews of Environ. Cont. and Toxicol.*, **117**, 1-49.
- Arnetz, B. and M. Nicolich, 1990. Modelling of environmental lead contributors to blood lead in humans. *Int. Arch. Occup. Environ. Health* **62**, 397-402.
- Bravo, H., L. Monkman, R. Nulman and T. Stanley, 1970. Concentrations of lead BzP and BKF in the atmosphere of three Mexican cities. Proc. 2nd. International Air Pollution Congress, Washington, D.C.
- Bravo, H., F. Perrin, R. Sosa and R. Torres, 1988. Incremento de la contaminación atmosférica en la Ciudad de México. *Ingeniería Ambiental* **1**, 8-14.
- Calderón, J., 1994. Aproximación a un Modelo Integral de exposición a plomo en niños de la Zona Centro de la Ciudad de México. Tesis de Maestría, Instituto Nacional de Salud Pública, México. P. 83.
- Chamberlain, A. C., 1983. Effect of airborne lead on blood lead. *Atmos. Environ.*, **17**, 677-692.
- Cicero-Fernández, P., 1991. Prioritizing air pollutant controls for urban centers in developing countries: Mexico City as a case study. Air Waste Management. 84th annual meeting and exhibition Vancouver, British Columbia, 91-115-10: 1-13.
- Duggan, M. J., M. J. Inskip, S. A. Runolle and J. S. Moorcroft, 1985. Lead in playground dust and on the hands of school children. *Sci. Total Environ.*, **44**, 65-79.
- Espinoza, M., Y. Falcón, S. Salazar and T. Espejel, 1978. Lead and cadmium concentrations in suspended particles in two sampling stations in Mexico City, 71st Air Pollution Cont. Assoc. Ann. Meet, pp. 786-794.
- Falcón, Y., C. Ramírez, H. Carrillo, J. López and J. Meza, 1986. Trace elements concentration and TSP as measured during the winter of 1983 and 1984 in Mexico City, 79th Air Pollut. Cont. Assoc. Ann. Meet., pp. 1-11.
- Friberg, L., 1988. Quality Assurance In: Biological monitoring of toxic. T. W. Clarkson, L. Friberg, G. F. Nordberg, P. P. Sager (Eds.) Plenum Press, New York.
- Goyer, R., 1993. Lead Toxicity: Currents concerns. *Environ. Health Perspect.*, **100**, 177-187.

- Gross, S. B., 1981. Human oral and inhalation exposures to lead: summary of Kehoe balance experiments. *J. Toxicol. Environ. Health* **8**, 333-377.
- Harrison R. M and C. R. Williams, 1982. Airborne cadmium lead and zinc at rural and urban sites in north-west England. *Atmospheric Environ.* **16**, 2669-2681.
- Hernández-Avila, M., I. Romieu, C. Ríos, A. Rivero and E. Palazuelos, 1991. Lead-glazed ceramics as major determinants of blood levels in Mexican women. *Environ. Health Perspect.*
- Hoaglin, D., F. Mosteller and J. Tukey, 1991. Fundamentals of Exploratory Analysis of Variance. John Wiley and Sons, Inc., New York.
- Jáuregui, E., 1986. The urban climate of Mexico City. Proceed WMO. Conf. on Urban Climate. Tec. Note WMO No. 652, 63-82, Geneva.
- Jáuregui, E. and C. Sánchez, 1987. Distribución espacial y temporal del plomo atmosférico en la Ciudad de México. Memorias de la II Reunión de Investigadores Universitarios en Contaminación Ambiental. Facultad de Medicina-UNAM, Mexico, D. F., pp. 24-29.
- Khanderkar, R. N., D. N. Kelak and K. G. Vohra, 1980. Lead, cadmium, zinc, copper and iron in the atmosphere of Greater Bombay. *Atmospheric Environ.* **14**, 457-461.
- Kretzschmar, J. G., 1992. Suspended particulate matter levels in the megacities of Latin America. Unpublished manuscript. ENE/NOOOO/JGK/hv-1/92-160.
- Lara-Flores, E., J. Alagon-Cano, J. L. Bobadilla, B. Hernández - Prado, B. and A. Ciscomani-Begoña, 1989. Factores asociados a los niveles de plomo en sangre en residentes de la Ciudad de México. *Salud Pública de México* **31**, 625-633.
- Morrow P. E., H. Berter, F. Amato, F. R. Gibb, 1980. Pulmonary retention of lead: an experimental study in man. *Environ. Res.* **21**, 373-384.
- PICA, 1990. Programa integral contra la contaminación atmosférica. Documento Criterio, Departamento del Distrito Federal. P. 75.
- Rapoport, H. E., Z. Diaz, E. M. Betancourt and R. I. López Moreno, 1983. Aspectos de la ecología urbana de la Ciudad de Mexico, Ed. Limusa, México.
- Robinson E. and F. L. Ludwig, 1967. Particle size distribution of urban lead aerosols. *J. Air Pollut. Control Assoc.* **17**, 664-669
- Romieu I., E. Palazuelos, M. Meneses and M. Hernández-Avila, 1992. Vehicular traffic as a determinant of blood-lead levels in children: A pilot study in Mexico City. *Archives of Environ. Health* **47**, 246-249.
- Romieu, I., L. López, T. Carreon-Valencia, T. Alejandro, E. Palazuelos, M. Ives and M. Hernández-Avila, 1993. Proceedings of the 6th International Conference on Indoor Air Quality and Climate **3**, 439-443.
- Salazar, S., H. Bravo and Y. Falcón, 1981. Sobre la presencia de algunos metales pesados en la atmósfera de Mexico. *Geofís. Int.* **20**, 41-54.
- SEDESOL-INE (Secretaría de Desarrollo Social-Instituto Nacional de Ecología), 1991-1992. Informe de la situación general en materia de equilibrio ecológico y protección al ambiente, pp. 158-159.
- SEDESOL-INE (Secretaría de Desarrollo Social-Instituto Nacional de Ecología), 1992. Regulación y gestión de productos químicos en México, enmarcados en el contexto internacional. Series Monográficas No.1, pp. 23-26.
- Shy, C. M., 1990. Lead in petrol: the mistake of the XXth century. *Rapp. trimest. statist. sanit. mond.*, **43**, 102-110.

- Sokal R. and J. Rohlf, 1969. *Biometry*. W. H. Freeman and Company, San Francisco.
- Solomon, P. A., T. Fall, L. Salmon, R. Glen, G. R. Cass, H. A. Gray and A. Davidson, 1989. Chemical characteristics of PM₁₀ aerosols collected in the Los Angeles Area. *JAPCA*, **39**, 154-163.
- Ter Haar G., D. Lenane, J. Hu and M. Brandt, 1972. Composition, size and control of automotive exhaust particulates. *JAPCA* **22**, 39-46.
- Thornton, I., D. Davies, J. Watt and M. Quinn, 1990. Lead exposure in young children from dust and soil in the United Kingdom. *Environ. Health Perspect.* **89**, 55-60.
- USEPA, 1982. The relationship between gasoline lead usage and blood lead levels in Americans: A statistical analysis of the NHANES II data. Contract No. 68-01-5845.
- USEPA, 1986. Air quality criteria, Vol. I-IV EPA 600/8-83/028CF. Research Triangle Park, N. C. 2771.
- UNEP/WHO, 1986. Guidelines for integrated air, water, food and biological exposure monitoring: Quality assurance in environmental pollution exposure monitoring. PEP/866 p. 92-115 World Health Organization, Geneva.
- Vahter M., M. Berglund, S. Slorach, L. Friberg, M. Saric, Z. Xingquan Z. and M. Fujita M., 1991. Methods for integral exposure monitoring of lead and cadmium. *Environ. Res.* **56**, 78-89.