Surveillance of Acute Health Effects of Air Pollution in Mexico City

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Background: A unique, active, timely, low-cost surveillance system for the metropolitan area of Mexico City was established in the mid-1990s.

Methods: The system obtained upper and lower respiratory tract symptoms and eye symptoms from daily interviews for a systematic sample of the general nonhospitalized population living within a 2-km radius of air pollution monitors during 1996-1997.

Results: Ozone increments (10 ppb) were associated with upper respiratory symptoms (odds ratio [OR] = 1.003; 95% confidence interval [CI] = 1.002-1.004) and ocular symptoms indicators (OR = 1.005; CI = 1.004-1.007), and with a higher risk of lower respiratory symptoms indicator among nonsmokers (OR = 1.003; CI = 1.002-1.005). Increases in relative humidity reduced the risk of increments of sulfur dioxide on the 3 acute health indicators. Association of PM_{10} with health indicators varied among the 5 regions. During emergency episodes, symptoms increased sharply when ozone reached 281 ppb, a finding that resulted in a change in the ozone criteria for emergency declaration from 294 to 281 ppb.

Conclusions: This system has been low cost, timely, and useful for local decision making.

Key Words: surveillance systems, air pollution, respiratory morbidity

(*Epidemiology* 2003;14: 536–544)

Epidemiologic studies have documented the association between air pollutants and acute health effects.[1-5] Reports from developed countries[6-8] have discussed the implementation of geographic information or monitoring systems for the study of the effects of air pollution on health, most of them based on hospital and clinical services. There are few examples of health surveillance systems from developing countries that provide systematic collection of health and pollution data and that are adapted to the local environmental characteristics and limited resources of the localities.

This report provides a general description of the surveillance system of acute effects for the Mexico City metropolitan area. We use data from 1996 and 1997, when the surveillance system was consolidated, to characterize the relation of air pollutant levels with symptoms and to describe the short-term health effects during emergency episodes.

METHODS

Air pollution control activities[9] directed toward large emission sources, vehicles, and industry were established during the early 1990s and are stricter during emergency episodes. The metropolitan area of Mexico City has an automatic environmental monitoring network that has monitored air quality since 1986. The network has 32 stations distributed throughout the 1320-km^2 area. This network reports average daily pollution levels for the central region and for the 4 large quadrants that together comprise the entire metropolitan area. However, not all network stations monitor the 5 criteria pollutants: carbon monoxide, particles, sulfur dioxide, nitrogen dioxide, and ozone.

The Ministry of Health also began the surveillance of health effects in the early 1990s only during emergency episodes.[10,11] Information that would be required to take immediate action was not easily accessible or available in a timely manner from healthcare facilities, and so a more active approach to health surveillance was undertaken. Finally, in 1995, the Epidemiologic Environmental Surveillance System began to monitor acute health effects on a daily basis. To define the surveillance regions it was necessary to select stations that monitored the 5 criteria pollutants. Furthermore, stations were located in the 5 regions to obtain health information according to the environmental reports.

Submitted 10 October 2001; final version accepted 16 May 2003.

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This study was supported by the Consejo de Estudios para la Restauración y Valoración Ambiental, Gobierno del Distrito Federal, and the Consejo Nacional de Ciencia y Tecnología, grant number 28989-M.

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1044-3983/03/1405-0536
DOI: 10.1097/01.ede.0000081801.90352.bf

Study Area and Sampling Scheme

The system has obtained cross-sectional information from personal interviews on a sample of residents living within a 2-km radius of one of the air-quality monitoring stations of the Mexico City basin. A systematic sampling approach was used daily to select 1 of every 2 households from a designated monitor area, that included between 20 and 40 housing blocks. On weekdays 1 or more monitoring areas were visited by teams of interviewers from 9 AM to 3 PM and on weekends when emergency episodes occurred. Selected households were visited up to 3 times on a single day in an effort to obtain a response. A new sample was selected each day. Over the 2-year period, an average of 290 interviews were obtained daily for the entire Basin, which included 74,000 homes.

All household residents aged 13 and older who were present when interviewers visited the household were invited to participate. Residents who accepted were interviewed at their home. Information for children less than 13 years old was obtained from the mother or another adult. These household interviews aimed to obtain a general descriptive overview of the potential health effects of exposure to air pollution in every age group. General nonresponse rate was 55%; of these, nobody was at home in 70% of the households, and interviews were refused by 25% of the households. Among the cooperating households, 168,715 interviews were completed with an average of 3 residents per household. After exclusion of cases with erroneous imputed dates or with erroneous data as derived from the combination of variables such as age, marital status, and schooling, 151,418 (90%) interviews were available for analysis.

The structured questionnaire included sociodemographic questions, self-reported respiratory and ocular symptoms present during the interview day and over the previous week, and chronic problems diagnosed by a physician over the past year. Current symptoms included head cold, dry cough, wet cough, sore throat, difficulty breathing, hoarseness, chest sounds, headache, eye irritation, eye burning, eye itching, eye infection, and teary eyes. Chronic problems included bronchitis, emphysema, and asthma. The database was submitted to weekly quality control processes to identify interviews with inconsistent data and to correct or eliminate these interviews.

Health Outcomes

To study the association of air pollutants and health outcomes, we selected interview data from the 1996-1997 period, the first 2 years during which the system conducted interviews on a daily basis. Three binary health outcome variables were created from the combination of acute symptoms: an upper respiratory symptom indicator that included wet cough, sore throat, hoarseness, nose dryness, and head cold; a lower respiratory symptom indicator, including dry cough, lack of air, and chest sounds; and an ocular symptom indicator that included eye irritation, eye itch, eye burning, teary eyes, red eyes, and eye infection. Indicators were coded positive when at least 1 symptom was present and negative otherwise.

Air Pollution and Meteorologic Data

Criteria pollutant and meteorologic data were obtained from the Automatic Environmental Monitoring Network. The air pollution metric was assigned to each individual based on the data measured on the same day by the nearest monitoring station. The Network produces hourly reports for the criteria pollutants. Ozone is measured by ultraviolet photometry, sulfur dioxide (SO_2) by pulsed fluorescence, nitrogen oxides (NO_2) by chemoluminescence, and particles with an aerodynamic diameter of 10 μm or less (PM_{10}) by gravimetric methods.

We declared missing values if more than 50% of the day's values for a pollutant or meteorologic variable were unavailable. Temperature was missing for 7.5% of the days and relative humidity for 7.1% of the days. All air pollution metrics were complete for the study period. Estimated metrics for study pollutants included 1- to 7-day lags of means, maximums, and cumulatives. Because the Mexican ozone standard is based on the 1-hour maximum, this metric was chosen for the analyses of symptoms during emergencies. Because of the relationship of ozone with solar radiation, we selected the ozone mean between 8 AM and 6 PM for the analyses of the health indicators. One-day lags were used for all analyses, because these provided the best fit in the initial analyses.

Analysis

We calculated descriptive statistics for each pollutant and correlations between the pollutant indicators. We used logistic regression models to assess the associations between pollutant levels and health outcomes.[12] All cases with nonmissing data were included. Pollutant quartiles were created to evaluate linearity on health outcomes. Pollutant metrics indicators were regressed on each health outcome indicator for each respondent adjusting for the following dummy covariates: sex, age (less than 15; 15-46; over 46), education (years of schooling less ≤9, over 9 y), cigarette smoking (no, yes), season (wet, dry), emergency episode mass media report (no, yes), temperature, and relative humidity. No other variables were significant in the univariate logistic regression models. Odds ratios (ORs) and 95% confidence intervals (CIs) were estimated for pollutant quartiles or for increments in 10 units. Covariates remained in the models if they accounted for a 10% or greater change in the logit. We tested interaction terms between air pollutants and smoking, and for 1 unit change in temperature or a 1-unit change in relative humidity.

RESULTS

More females than males responded to the interview; 29% of the respondents were less than 15 years old, 48% between 15 and 46 years, and 23% age 47 and older. Eighty-one percent of the interviewees had between 6 and 9 years of formal education, 13% had more than 9 years, and 6% had less than 6 years of education. During the study period, 6 emergencies were declared because of high ozone levels, totaling 21 contingency days.

A descriptive summary of the air pollutant levels and meteorologic data for the 2-year period is presented in Table 1. Differences in pollutant levels are observed across the city, with higher ozone values in the 2 southern regions and higher PM_{10} values in the northeast. SO_2 values were higher in the northeast and NO_2 in the central and southwest regions. Ozone and PM_{10} means were higher during the dry months compared with the wet months (data not shown). Temperature variations of around 1°C were observed between regions, whereas the central region had the highest relative humidity.

The correlations between the various ozone measures (24-h mean, 1-h maximum, 8-18 h maximum, 8-18 h mean) were high (>0.85) (Table 2). Other correlation measures were lower.

Figure 1 shows the overall prevalence of symptoms during the 3-day emergency episode beginning on April 29, 1997, when the ozone rose to 309 ppb. On the day when the emergency began (April 29) the headache prevalence was double (22%) the base mean of the previous 7 days (11%); and prevalence decreased on the following day (April 30) when the maximum ozone dropped to 228 ppb. A similar but less dramatic trend was observed for sore throat, which increased from 11 to 15% and declined to 14% on the second day of the emergency. An increase in dry cough was seen (from 8% to 12%) on the day of the emergency and decreased thereafter. Difficulty breathing and dry cough also increased on April 29 and decreased on April 30. The decreasing symptom tendency on the following 2 days (April 30 and May 1) served as support for ending the emergency and for terminating the stricter control measures.

Prevalence measures were graphed against the maximum 1-hour daily ozone for the 2-year period to establish how symptoms responded to ozone increments (Fig. 2).

TABLE 1. Air Pollution and Meteorologic Parameter Statistics by Region of Residence for 504 Days With Interviews, Metropolitan Area of the Mexico City Basin, 1996-1997

	Region of Residence								
	Northeast			Northwest			Central		
	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum
Ozone 8:00–18:00 h* (ppb)	25 (9)	5	54	30 (12)	4	68	27 (11)	3	64
Ozone 1-hour maximum (ppb)	102 (39)	19	205	121 (53)	16	263	118 (46)	12	242
PM_{10} (μg/m^3)	132 (52)	34	269	87 (46)	10	275	85 (37)	9	319
SO_2 (ppb)	22 (12)	5	96	19 (9)	6	99	17 (10)	4	103
NO_2 (ppb)	38 (15)	16	119	42 (16)	11	93	42 (17)	6	90
Temperature	17 (2)	9	22	16 (2)	9	22	17 (2)	9	22
Relative humidity	43 (12)	17	71	48 (15)	11	82	56 (12)	18	87

	Region of Residence					
	Southeast			Southwest		
	Mean (SD)	Minimum	Maximum	Mean (SD)	Minimum	Maximum
Ozone 8:00–18:00 h* (ppb)	35 (13)	6	80	31 (13)	3	78
Ozone 1-hour maximum (ppb)	119 (43)	23	236	140 (58)	12	291
PM_{10} (μg/m^3)	79 (35)	14	225	55 (28)	12	264
SO_2 (ppb)	12 (7)	4	74	12 (6)	4	59
NO_2 (ppb)	27 (9)	6	76	43 (16)	11	99
Temperature	16 (2)	9	21	16 (2)	9	21
Relative humidity	41 (10)	13	63	49 (13)	14	82

*8 AM–6 PM.
SD, standard deviation; ppb, parts per billion.

TABLE 2. Daily Air Pollutant Pearson Correlation Coefficients

	Ozone Mean	Ozone 8:00–18:00 h Mean	SO_2 Mean	NO_2 Mean	PM_{10} Mean	Temperature Mean	Relative Humidity Mean
Ozone mean	1.0						
Ozone 8:00–18:00 h mean	0.965	1.0					
SO_2 mean	−0.035	−0.019	1.0				
NO_2 mean	0.253	0.302	0.196	1.0			
PM_{10} mean	0.067	0.075	0.265	0.265	1.0		
Temperature mean	0.089	0.021	−0.121	−0.132	0.088	1.0	
Relative humidity mean	−0.325	−0.303	−0.081	−0.111	−0.324	0.000	1.0

Increases in symptoms (teary eyes, sore throat, headache and eye irritation) are observed; 1 when ozone reached between 159 and 183 ppb, the second when it reached between 208 and 232 ppb, and the third when it reached above 281 ppb. The increasing pattern was observed for all symptoms, although teary eyes and eye irritation showed the largest increments. This type of information was the foundation for more stringent criteria for ozone emergency declarations, which was redefined at 281 ppb during 1997.

Two-year average prevalence rates for the entire metropolitan area were 24% for the upper respiratory symptom indicator, 10% for the lower respiratory symptom indicator, and 19% for the ocular symptom indicator. The elderly, females, smokers, and persons not living in the northern regions had higher odds ratios for the 3 indicators (Table 3). The risk estimates rose steadily with increases in ozone and NO_2, whereas the associations for SO_2 and PM_{10} decreased in the fourth quartile. Preliminary logistic regression models showed variations by region only for PM_{10}. Based on this information, we carried out analyses by region only for PM_{10}. For SO_2 the analysis was done for relative humidity quartiles.

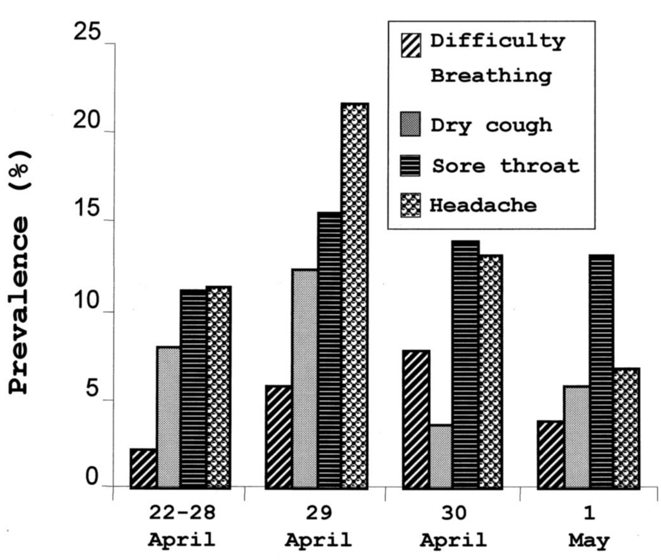

FIGURE 1. Symptom prevalence for the April 29-May 1, 1997 emergency and the preceding days (base period) metropolitan area of the Mexico City Basin. Daily 1-hour maximum ozone was 14 ppb for the base period; and 309, 228, and 137 ppb for April 29, April 30, and May 1, respectively.

The Effects of Air Pollutants

Results of the logistic regression models for the upper and lower respiratory symptoms indicators and the ocular symptoms indicators are shown in Table 4. Increasing levels of ozone and nitrogen dioxide were associated with the indicators. The strongest effects of sulfur dioxide are for ocular symptoms at 25% relative humidity. In general, the risk of all 3 indicators decreases as relative humidity increases.

Increasing levels of PM_{10} were not associated with the upper respiratory symptoms indicator in most regions, although there was some evidence of an association in the central region (Table 5). The risk of lower respiratory symp-

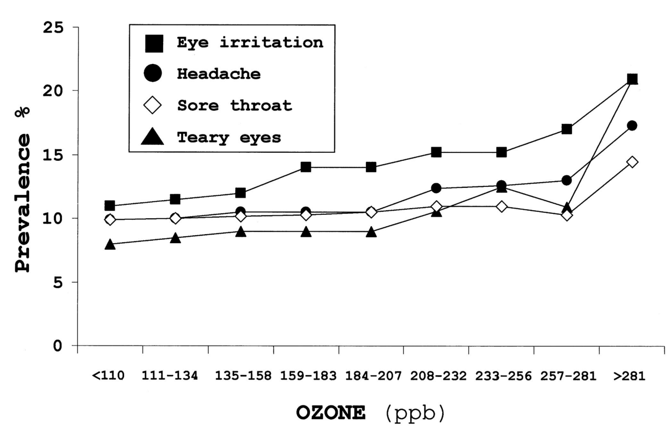

FIGURE 2. Average symptom prevalence and daily 1-hour maximum ozone levels for the metropolitan area of the Mexico City Basin, for the 2-year study period (1996-1997).

TABLE 3. Health Indicators by Various Characteristics, Including Air Pollution

	Upper Respiratory Indicator		Lower Respiratory Indicator		Ocular Indicator	
	OR	95% CI	OR	95% CI	OR	95% CI
Age (y)						
Young (≤15)	0.87	(0.84–0.89)	1.19	(1.14–1.24)	0.44	(0.42–0.45)
Adults (16–46)*	1.0		1.0		1.0	
Elderly (>46)	1.18	(1.14–1.21)	1.57	(1.51–1.63)	1.41	(1.36–1.45)
Sex						
Females*	1.0		1.0		1.0	
Males	0.82	(0.80–0.84)	0.87	(0.84–0.90)	0.78	(0.76–0.80)
Years of education						
≤6	0.75	(0.73–0.78)	1.01	(0.96–1.07)	0.97	(0.93–1.01)
7–12	0.81	(0.78–0.84)	0.87	(0.83–0.92)	0.86	(0.82–0.89)
>12*	1.0		1.0		1.0	
Cigarette smoking						
No*	1.0		1.0		1.0	
Yes	1.31	(1.26–1.36)	1.41	(1.34–1.48)	1.58	(1.52–1.64)
Season						
Wet*	1.0		1.0		1.0	
Dry	1.61	(1.57–1.65)	1.58	(1.53–1.64)	1.34	(1.31–1.38)
Emergency episode						
No*	1.0		1.0		1.0	
Yes	1.36	(1.27–1.45)	1.44	(1.32–1.58)	1.57	(1.46–1.68)
Region of residence						
Northwest*	1.0		1.0		1.0	
Northeast	0.80	(0.77–0.83)	1.01	(0.95–1.07)	0.88	(0.84–0.92)
Central	1.10	(1.06–1.14)	1.13	(1.07–1.19)	1.12	(1.07–1.17)
Southeast	1.02	(0.99–1.06)	1.07	(1.02–1.13)	0.94	(0.90–0.98)
Southwest	1.27	(1.22–1.32)	1.18	(1.12–1.25)	1.55	(1.49–1.62)
Ozone quartiles						
2.96–21.33*	1.0		1.0		1.0	
21.34–29.08	1.03	(1.00–1.07)	1.02	(0.97–1.07)	1.08	(1.04–1.12)
29.09–37.08	1.09	(1.06–1.13)	1.10	(1.05–1.15)	1.14	(1.10–1.18)
37.09–79.20	1.13	(1.10–1.17)	1.12	(1.07–1.17)	1.25	(1.21–1.30)
NO_2 quartiles						
5.46–25.4*	1.0		1.0		1.0	
25.5–33.2	1.05	(1.01–1.08)	1.04	(0.99–1.03)	1.10	(1.06–1.14)
33.3–45.1	1.11	(1.07–1.15)	1.07	(1.02–1.12)	1.18	(1.14–1.23)
45.2–119.5	1.30	(1.26–1.34)	1.22	(1.16–1.27)	1.42	(1.37–1.47)
SO_2						
3.0–9.7*	1.0		1.0		1.0	
9.8–13.3	1.06	(1.03–1.10)	1.05	(1.00–1.10)	1.12	(1.08–1.16)
13.4–19.2	1.18	(1.14–1.22)	1.20	(1.14–1.26)	1.23	(1.18–1.27)
19.3–103.0	1.12	(1.08–1.16)	1.14	(1.09–1.20)	1.06	(1.02–1.10)
PM_{10} quartiles						
10.04–52.62*	1.0		1.0		1.0	
52.63–73.58	1.02	(0.99–1.06)	1.04	(0.99–1.09)	0.99	(0.95–1.03)
73.59–101.91	1.07	(1.03–1.10)	1.09	(1.04–1.14)	0.89	(0.86–0.92)
101.92–318.80	0.93	(0.90–0.97)	1.03	(0.98–1.08)	0.84	(0.81–0.87)

*Reference category.
OR, odds ratio; CI, confidence interval.

TABLE 4. Adjusted Logistic Regression Results for 3 Acute Health Indicators by Ozone, Sulfur Dioxide, and Nitrogen Dioxide

	Upper Respiratory Indicator		Lower Respiratory Indicator		Ocular Indicator	
	OR	95% CI	OR	95% CI	OR	95% CI
Ozone						
Main effects*†	1.003	(1.002–1.004)		—	1.005	(1.004–1.007)
Among smokers		—	1.001	(0.997–1.005)		—
Among nonsmokers		—	1.003	(1.002–1.005)		—
NO_2*†						
Main effects	1.002	(1.001–1.003)	1.001	(1.000–1.002)	1.004	(1.002–1.007)
SO_2 at 25% relative humidity‡						
2nd quartile	1.093	(0.958–1.247)	1.135	(0.938–1.372)	1.301	(1.125–1.506)
3rd quartile	1.081	(0.950–1.229)	1.217	(1.012–1.463)	1.303	(1.129–1.504)
4th quartile	1.059	(0.928–1.209)	1.198	(0.991–1.447)	1.235	(1.064–1.434)
SO_2 at 50% relative humidity‡						
2nd quartile	0.964	(0.845–1.100)	0.987	(0.816–1.190)	1.051	(0.909–1.216)
3rd quartile	1.023	(0.900–1.164)	1.046	(0.870–1.257)	1.115	(0.966–1.286)
4th quartile	0.971	(0.850–1.108)	1.001	(0.828–1.210)	0.981	(0.846–1.139)
SO_2 at 75% relative humidity‡						
2nd quartile	0.851	(0.746–0.970)	0.858	(0.710–1.038)	0.849	(0.734–0.982)
3rd quartile	0.969	(0.852–1.102)	0.899	(0.747–1.081)	0.953	(0.826–1.100)
4th quartile	0.890	(0.779–1.016)	0.836	(0.692–1.011)	0.780	(0.672–0.905)

*Adjusted for sex, age, education, tobacco smoking, mass media emergency information, temperature, relative humidity, and season. One-day lag used for pollutant measures. Ozone measure = ozone 8:00–18:00 h mean.

†10 parts per billion increases.

‡SO_2 part per billion quartiles: 1st 3.0–9.7; 2nd 9.8–13.3; 3rd 13.4–19.2; 4th 19.3–103.0. First quartile is reference category.

OR, odds ratio; CI, confidence interval.

toms indicator increased in the northwest and southwest, but the association was not linear in the latter region. The effects of particulate matter on the lower respiratory symptoms indicator in the northeast region and the ocular symptoms indicator in the southeast region showed an inverse association.

DISCUSSION

This study describes how the Epidemiologic Environmental Surveillance System of the metropolitan area of the Mexico City Basin was used in the decision-making process for air emergencies. We also examined the association between air pollutants and acute health effects among a sample of the apparently healthy general population. Effects of ozone, SO_2, and NO_2 on upper and lower respiratory symptoms indicators and on ocular symptoms were observed, in agreement with other reports.[2,13-15] The size of the point estimates were large, suggesting that the potential public health burden of respiratory and ocular discomforts attributable to the prevailing air pollution mixture prevalent in the metropolitan area of Mexico City during the 1996-1997 period was considerable.

Daily health data for the Surveillance System have been collected without interruption since the end of 1995; by the end of the year 2001 more than 500,000 interviews had been obtained. Prevalence fluctuations, associated with variations in air pollutants, have been used by the authorities to define interventions with the aim of protecting the health of the population. Based on this information, the ozone level used to declare an emergency was reduced slightly, from 294 to 281 ppb.

The Surveillance System provides a first-hand approximation of the short-term health effects resulting from air pollution in the general population. Many studies dealing with environmental pollution have focused on severe health effects such as asthma, chronic diseases, hospitalizations, or mortality. Little is known, however, about disorders that might be experienced by a large proportion of the population but which are not routinely considered by conventional epidemiologic surveillance. The importance of acute adverse

TABLE 5. Adjusted* Logistic Regression Results for PM_{10} for 3 Acute Health Indicators by Region of Residence

	Upper Respiratory Symptom Indicator		Lower Respiratory Symptom Indicator		Ocular Symptom Indicator	
	OR	95% CI	OR	95% CI	OR	95% CI
Northeast						
PM_{10} main effects‡						
2nd quartile	0.354	(0.112–1.222)	0.215	(0.040–1.160)	1.080	(0.915–1.274)
3rd quartile	0.118	(0.039–0.356)	0.126	(0.023–0.690)	1.228	(0.720–2.095)
4th quartile	0.095	(0.034–0.267)	0.119	(0.026–0.549)	0.878	(0.619–1.246)
Northwest						
PM_{10} main effects‡						
2nd quartile	0.990	(0.898–1.090)	1.246	(1.087–1.429)	1.218	(0.808–1.834)
3rd quartile	1.133	(0.974–1.317)	1.202	(1.044–1.385)	0.345	(0.125–0.951)
4th quartile	1.019	(0.904–1.149)	1.344	(1.137–1.589)	1.949	(1.416–2.683)
Central						
PM_{10} main effects‡						
2nd quartile	1.088	(1.002–1.183)	1.046	(0.930–1.176)	1.220	(1.115–1.335)
3rd quartile	1.054	(0.977–1.137)	1.055	(0.948–1.175)	1.049	(0.965–1.142)
4th quartile	0.899	(0.826–0.979)	0.952	(0.845–1.073)	0.875	(0.796–0.963)
Southeast						
PM_{10} main effects‡						
2nd quartile	0.778	(0.575–1.052)	1.047	(0.916–1.196)	0.460	(0.299–0.708)
3rd quartile	1.297	(1.127–1.491)	1.391	(1.131–1.711)	0.474	(0.314–0.715)
4th quartile	0.893	(0.812–0.983)	0.937	(0.818–1.073)	0.314	(0.182–0.542)
Southwest						
PM_{10} main effects‡						
2nd quartile	0.987	(0.913–1.066)	2.181	(1.177–4.040)	1.026	(0.928–1.135)
3rd quartile	0.673	(0.673–1.886)	0.899	(0.790–1.024)	1.017	(0.862–1.200)
4th quartile	0.524	(0.524–1.787)	4.346	(0.917–20.606)	0.187	(0.090–0.387)

PM_{10} = particles with an aerodynamic diameter of 10 μm or less.
*Adjusted for sex, age, education, smoking, mass media emergency information, temperature, relative humidity, and season.
‡PM_{10} quartiles: 1st 10.04–52.62; 2nd 52.63–73.58; 3rd 73.59–101.91; 4th 101.92–318.80. First quartile is reference category.
OR, odds ratio; CI, confidence interval.

health responses lies in the fact that all who are exposed could in time be affected, leading to possible hospitalizations among the highly susceptible. Among the less susceptible, there could be general malaise, transient symptoms, use of medications to relieve symptoms, short-term absence from work, or decreased productivity.[16,17]

The establishment of an Epidemiological Surveillance System for the Mexico City Basin, a highly polluted area inhabited by over 12 million people, has provided useful local information on acute health conditions. Monitoring severe effects involving hospitalizations or mortality is more costly and requires a longer time span for data collection and analysis. We think this approach to data collection might represent the best balance between available resources and data requirements because it is simple, low cost, representative, timely, and flexible. This Surveillance System is also useful for local decision making, as shown by the fact that it led to the modification of air pollution levels for emergency episode declaration and provided a quantitative estimate of the magnitude of air pollution-related morbidity.[18,19] A similar environmental surveillance system was established in Hungary[20] to assess the association between air pollution and reportable physician-diagnosed respiratory diseases in children, the results of which were also used to implement local pollution control measures.

Similar to other reports, our data illustrate that ozone, SO_2, and NO_2 induce airway inflammation affecting the respiratory tract[21] and eyes, and that the effects of PM_{10} varied according to the region of residence. The sources of air pollution within the Mexico City Basin differ by region. In the northeast particulate matter predominates; in the northwest pollution composition is predominantly industrial; and in the central and southern regions, which are residential, the combustion of motor-vehicle fuels is the major source of air pollution. Because the network does not provide type of particles, further studies would be needed to confirm short-term specific particulate PM_{10} health effects.

Our results indicate that ozone might produce a higher negative response among nonsmokers compared with smokers. Frampton et al.[21] found fewer respiratory symptoms among smokers exposed to ozone than among nonsmokers. Shephard et al.[22] also observed a decrease in lung function among smokers and nonsmokers exposed to chamber ozone; however, response among smokers was less sharp than that of nonsmokers. They suggest that chronic smoking could delay the effect of ozone on the lower respiratory tract.

Another interesting result was the interaction between SO_2 and relative humidity. According to our data, SO_2 could reach a saturation point at 25% relative humidity. Higher relative humidity would dilute the acidity of the resulting sulfuric acid, which could be less irritative to the mucosa.[23,24]

This study does have some limitations. Temporality, an important weakness of cross-sectional designs, was addressed to some extent by the use of the 1-day lagged exposures in the regression models. As has been discussed in previous reports,[5,25,26] the pollutant values obtained from fixed monitoring stations such as those used here probably overestimate exposure for persons who remain indoors and underestimate exposure for persons performing strenuous outdoor activities such as sports. We assumed that within regions all who were at home were exposed to similar air pollution levels and that their health status represents an estimate of the health of the population at risk. Under these situations our results might be biased toward the null, because misclassification of exposure was nondifferential between the ill and the healthy subjects. Furthermore, we could not take into account correlation within households because it is not possible to link family members in this dataset; therefore, variances might be underestimated.

Data on pollen or mold were not collected and data on other health events, such as acute respiratory infectious diseases or influenza epidemics, were not available. Thus, we could not assess whether these variables might have confounded the observed relationships or acted as intervening variables. Future research should incorporate information on these factors. The effects of NO_2 on women's health[14] resulting from the use of liquid petroleum gas in cooking might represent an additional potential source of exposure. Personal monitoring among housewives or monitoring inside the homes would be required to quantify its effects, but personal monitoring was beyond the capacity of this surveillance system.

Schwartz and Morris[27] have suggested that changes in behavior could occur on days with high pollution that affects visibility. In Mexico City days with low visibility are frequent. A potential source of bias might have been related to mass media reports on high pollution days with low visibility when people could tend to overreport symptoms, leading to potential nondifferential misclassification. Hoek and Brunekreef[28] in The Netherlands and Cohen and colleagues in New York[29] did not detect a bias that strengthened the association of air pollution and symptoms resulting from media information. Questions related to air conditioning units in the homes were unnecessary because their use in Mexico City homes is rare.

Over the 2-year period, at least 1 interview was obtained from 75% of the households in which the door was answered. However, no data were available to compare sociodemographic characteristics for respondents and nonrespondents. The large proportion of female interviewees over 15 years of age probably reflects the greater participation of men in the labor force in the metropolitan area compared with women.[30] A possible overrepresentation of ill individuals who remained at home on the day of the interview might have biased the outcomes away from the null. Finally, the true magnitude of the pollutant's effect on children's health could have been underestimated, particularly for ocular symptoms, because such symptoms might have been less obvious to the adults who provided information on the children's health status.

Health data were not validated by physicians, so misclassification of outcomes might be present. The effect of this potential misclassification should have been nondifferential between the exposed and the nonexposed. Validation of the health status on a sample of interviewees should be considered as a part of future monitoring efforts.

In conclusion, this report describes the results of one of the first surveillance systems established in a developing country for the study of the effects of air pollution on health. The surveillance of acute changes in respiratory and ocular morbidity and of meteorologic variables should alert health and environmental authorities of an approaching situation that could increase air pollutants to emergency levels so that well-timed campaigns directed toward the prevention of health effects can be implemented.

ACKNOWLEDGMENTS

We thank Siobán Harlow for her helpful comments on the manuscript.

REFERENCES

1. Anderson HR, Limb ES, Bland JM, et al. Health effects of an air pollution episode in London, December 1991. *Thorax*. 1995;50:1188–1193.
2. Burnett RT, Dales RE, Raizenne ME, et al. Effects of low ambient levels of ozone and sulfates on the frequency of respiratory admissions to Ontario hospitals. *Environ Res*. 1994;65:172–194.
3. Ostro BD, Lipsett MJ, Mann JK, et al. Air pollution and respiratory morbidity among adults in Southern California. *Am J Epidemiol*. 1993;137:691–700.
4. Qian Z, Chapman RS, Tian Q, et al. Effects of air pollution on children's respiratory health in three Chinese cities. *Arch Environ Health*. 2000;55:126–133.

5. Hernández-Garduñno E, Pérez-Neria J, Paccagnella AM, et al. Air pollution and respiratory health in Mexico City. *J Occup Environ Med*. 1997;39:299–307.
6. Pikhart H, Prikazsky V, Bobak M, et al. Association between ambient air concentrations of nitrogen dioxide and respiratory symptoms in children in Prague, Czech Republic. Preliminary results from the Czech part of the SAVIAH Study. Small area variation in air pollution and health. *Cent Eur J Public Health*. 1997;5:82–85.
7. Anderson HR, Quenel P, Katsouyanni K, et al. Recommendations for the monitoring of short-term health effects of air pollution: lessons from the APHEA Multi Centre European Study. *Zentralbl Hyg Umweltmed*. 1999;202:471–488.
8. Zeghnoun A, Eilstein D, Saviuc P, et al. Surveillance des effets à court terme de la pollution atmosphérique sur la mortalité en milieu urbain. Résultats d'une étude de faisabilité dans 9 villes françaises. *Rev Epidémiol et Santé Publ* 2001;49:3–12.
9. Gobierno Constitucional de los Estados Unidos Mexicanos. *Normas Oficiales Mexicanas para ozono, monóxido de carbono, bióxido de azufre, bióxido de nitrógeno y partículas menores de 10 micras.* Diario Oficial de la Federación, México. Secretaría de Salud. Tomo CDXCV No. 16, 23 de diciembre de 1994, páginas 45-65.
10. Departamento del Distrito Federal, Gobierno del Estado de México, SEMARNAP, SSA. *Programa para mejorar la calidad del aire en el valle de México, 1995-2000.* Departamento del Distrito Federal; 1996.
11. Departamento del Distrito Federal. Secretaría del Medio Ambiente. *Informe Anual de la Calidad del Aire en el Valle de México.* Departamento del Distrito Federal; 1997.
12. Hosmer DW, Lemeshow S. *Applied Logistic Regression.* John Wiley and Sons, Inc; 2000.
13. Sunyer J, Antó JM, Murillo C, et al. Effects of urban air pollution on emergency room admissions for chronic obstructive pulmonary disease. *Am J Epidemiol*. 1991;134:277–286.
14. Koo LC, Ho JH-C, Ho C, et al. Personal exposure to nitrogen dioxide and its association with respiratory illness in Hong Kong. *Am Rev Respir Dis*. 1990;141:1119–1126.
15. Pikhart H, Bobak M, Kriz B, et al. Outdoor air concentrations of nitrogen dioxide and sulfur dioxide and prevalence of wheezing in school children. *Epidemiology*. 2000;11:153–160.
16. Lebowitz MD. Epidemiological studies of the respiratory effects of air pollution. *Eur Respir J*. 1996;9:1029–1054.
17. Ostro BD, Rothchild S. Air pollution and acute respiratory morbidity: an observational study of multiple pollutants. *Environ Res*. 1989;50:238–247.
18. Corey G. *Vigilancia en epidemiología ambiental. 1 Serie Vigilancia.* Centro Panamericano de Ecología Humana y Salud, División de Salud y Ambiente. Organización Panamericana de la Salud. Organización Mundial de la Salud; 1995.
19. Thacker SB, Parrish RG, Throwbridge FL, Surveillance Coordination Group. A method for evaluating systems of epidemiological surveillance. *World Health Statist Quart* 1988;41:11–18.
20. Agocs MM, Rudnai P, Etzel RA. Respiratory disease surveillance in Hungary. *MMWR*. 1992;41:1–8.
21. Frampton MW, Morrow PE, Torres A, et al. Ozone responsiveness in smokers and nonsmokers. *Am J Respir Crit Care Med*. 1997;155:116–121.
22. Shephard RJ, Urch B, Silverman F, et al. Interaction of ozone and cigarette smoke exposure. *Environ Res*. 1983;31:125–137.
23. Amdur MO. Respiratory absorption data and SO_2 dose-response curves. *Arch Environ Health*. 1966;12:729–732.
24. Schlesinger RB. Toxicology of sulfur oxides. In: Holgate ST, Samet JM, Koren HS, et al., eds. *Air Pollution and Health*. New York: Academic Press; 1999:585–602.
25. Romieu I, Meneses F, Sierna-Monge JJ, et al. Effects of urban air pollutants on emergency visits for childhood asthma in Mexico City. *Am J Epidemiol*. 1995;141:546–553.
26. Borja-Aburto VH, Loomis DP, Bangdiwala SI, et al. Ozone, suspended particulates, and daily mortality in Mexico City. *Am J Epidemiol*. 1997;145:258–268.
27. Schwartz J, Morris R. Air pollution and hospital admissions for cardiovascular disease in Detroit, Michigan. *Am J Epidemiol*. 1995;142:23–35.
28. Hoeck G, Brunekreef. Effect of photochemical air pollution on acute respiratory symptoms in children. *Am J Respir Crit Care Med*. 1995;151:27–32.
29. Cohen AA, Nelson CJ, Bromberg SM, et al. Symptom reporting during recent publicized and unpublicized air pollution episodes. *Am J Public Health*. 1974;64:442–449.
30. Instituto Nacional de Estadística, Geografía e Informática. *XII Censo General de Población y Vivienda 2000. Tabulados Básicos por Entidad Federativa.* Secretaría de Gobernación; 2002.

