WORKING PAPER

Health Impacts of Air Pollution on Morbidity and Mortality Among Children of Ciudad Juárez, Chihuahua, Mexico

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Abstract

Various studies conducted in Latin America provide evidence of the adverse effect of air pollution on health in different population groups. Few studies, however, have focused on young children and none have evaluated the impact of air pollution on groups of children that may be more vulnerable because of poor living conditions. We conducted a study in Ciudad Juárez, Mexico, a city located on the US-Mexico Border in the state of Chihuahua, to determine the impact of the air pollutants PM_{10} and ozone on the respiratory health of children. One of the main characteristics of Ciudad Juárez is the migratory flow across the border, mainly due to the increasing maquiladora industry and the rapid increase in the population with unplanned settlement.

In this study, we observed significant associations between ozone ambient levels and respiratory-related emergency visits by children. These associations were present for upper respiratory infections and asthma in all age groups. However, in children aged five years or less, ozone exposure was also related to lower respiratory infections (LRI) with a four-day lag. An increment of 20 ppb in the maximum 8-hr moving average four days prior to the visit was related to a 12.7% increase in the risk of LRI (95% CI 4.2% to 21.9%). Considering an increase of 20 ppb in 1-hr daily maximum over five days prior to the visit, the risk was 15% (95% CI 2.3% to 29.4%). No association was observed with PM_{10} ambient levels. These results remained similar in multipollutant models including ozone as well as PM_{10}.

Overall, ambient air pollutants were not related to respiratory deaths in our population of children. However, there was some suggestion that PM_{10} ambient levels might increase the risk of respiratory mortality among infants (>1 month to 1 year). When data were stratified by socio-economic status (SES), an increase in respiratory mortality was observed among infants from the lowest SES group (tables 20-21). Among infants aged one month to one year, a 20 $\mu g/m^3$ increase in PM_{10} 24-hr average on the previous day was associated with a 62% increase in respiratory mortality (95% CI 10% to 140%). When an increase of 20 $\mu g/m^3$ was observed on the two previous days, the risk of death was increase by 82% (95% CI 1% to 228%). However, these estimates were based on only 41 deaths. No increased mortality was observed in the higher SES. These results remained similar in multipollutant models including ozone as well as PM_{10}.

Mexico, as well as other developing countries, has a large urban population of children who live in poor conditions. Children, in particular young children, are a sector of the population susceptible to environmental threats because of their behavior and a reduced capacity to metabolize toxic substances (21). In addition to physiologic vulnerabilities, many children in Latin America have great social vulnerabilities related to poverty, malnutrition, and poor environment that both increase their exposure to contaminants and their susceptibility to the effects of contaminants (22). In addition, increases of respiratory morbidity and mortality were observed at air pollution levels commonly observed in urban areas in the region. Therefore, our results emphasize the need for the implementation of cost effective interventions to control existing air pollution problems and prevent the existing situation from worsening.

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1 Background

Mexico, along with the entire Latin America region, has a large population of children. In Latin America as a whole, children younger than 15 years of age represent approximately 12% of the population and children younger than five years of age represent close to 9%. Considering that 75% of these children reside in urban areas, the potential health impact caused by air pollution is large. In addition, poverty, malnutrition and unhealthy environmental conditions are highly prevalent, which may increase both exposure to contaminants and children's susceptibility to the effects of contaminants.

Various studies conducted in Latin America provide evidence of the adverse effect of air pollution on public health in different population groups (1—numbers in parentheses refer to works cited in reference list). Few studies, however, have focused on young children and none have evaluated the impact of air pollution on groups of children that may be more vulnerable because of poor living conditions. This is important because there is a need for a fair assessment of the impact of air pollution on children's health, accounting for factors that increase vulnerability, such as social inequality, in order to support public policies for prevention and control among the most disadvantaged populations.

In this project we evaluated the impact of air pollutants on children's health in Ciudad Juárez, Chihuahua, Mexico, focusing on groups that have different living conditions as estimated by their socio-economic status (SES). We studied two major health outcomes, mortality and morbidity, and their relation to ambient air pollutant levels of particulate matter less than 10 μm and ozone. The results obtained provide information on the adverse health effect of air pollution among children. The number of cases attributable to air pollution can then be calculated in order to provide decision makers with an estimate of the burden of diseases associated with this environmental threat among children who are vulnerable because of their living conditions.

2 Project Goals and Objectives

2.1 Project goal

The main goal of this project was to provide estimates of the health impacts of air pollution on children's respiratory health and determine if living conditions, as defined by socio-economic status, modified their vulnerability to this environmental threat. Our study population was composed of children residing in Ciudad Juárez, Chihuahua, Mexico, a city located on the US-Mexico border that has a large population of children and diverse social economic strata and living conditions.

2.2 Overall objective

The overall objective is to determine the health effects of air pollution among children with different living conditions, with particular attention paid to the impact of social inequity on health outcomes. Outcome variables included respiratory mortality as well as total respiratory morbidity and morbidity for upper respiratory infection (URI), lower respiratory infection (LRI), and asthma. These data allow a fair impact assessment of ambient air pollution on our children's population respiratory health and can be used to determine the burden of disease associated with air pollution, to support a knowledge-based process for making decisions for the prevention and control of air pollution.

2.3 Specific objectives

- To use the databases developed by the INSP under a previous CEC contract to estimate spatial maps of the relative rates of child mortality and respiratory morbidity associated with air pollution, while accounting, if necessary, for the spatial and temporal correlation in the data.
- To assess the relationship between air pollution and child mortality and respiratory morbidity among subgroups of the population, defined by age and different socio-economic characteristics and living conditions.
- To estimate the health impact of air pollution on children's health, based on the dose-response and exposure estimates obtained in the previous steps.
- To disseminate the results and provide these estimates to the health and air quality authorities in order to support preventive and control measures, with an emphasis on the most vulnerable populations.

3 Methods

We conducted a pilot project to determine the burden on children's health attributable to outdoor air pollution. Using a standardized method, we evaluated the impact of air pollution on children's total and respiratory mortality and morbidity in Ciudad Juárez, Chihuahua, Mexico. These results can then be used to determine the health benefit of clean air interventions using methodologies that can be extended to other cities in Mexico and comparable to studies in the United States and Canada.

Ciudad Juárez, Chihuahua is one of the most important cities on the border of the United States of America, with unique geographic conditions. This city represents 1.5% of the total area of Chihuahua and it is next to Texas and New Mexico. Ciudad Juárez, El Paso, Texas, and Sunland Park, New Mexico, all share a common atmospheric zone. Air pollution can go from one city to another according to the wind direction in the area.

Ciudad Juárez is situated on 188 km^2 of flat surface, with a trend for growth from east to south. Ciudad Juárez has a traffic system connecting different areas of the city, and has two main roadways that connect the city with the southern part of the country. One of these roads is the

Pan-American freeway and the other one is the Casas Grandes freeway. According to the Municipal Institute for Planning and Investigation, in 1997 the city's roadways consisted of 3,069 total kilometers, approximately half of them paved. Several of the roadways suffer from deteriorated conditions, as well as the fact that some of them are unfinished. These situations produce severe traffic congestion and increased air pollution, which is made worse because of a deteriorated vehicular fleet. In 1996, there were about 600,000 trucks and 15 million cars using the main border bridges between Ciudad Juárez and the USA. In 1997, a total of 662,000 tons of pollution were released into the atmosphere, 72% corresponding to CO, 10% corresponding to HC, 9.6% corresponding to PM_{10}, 5.2% corresponding to NO_2, 2.25% to SO_2 and 0.02% to lead (Pb). Most of the emissions were related to mobile sources (83.7%), with 5% to industries and 2.5% to services and commerce. The remaining corresponded to natural sources.

The total population in Ciudad Juárez is about one million inhabitants; this figure represents 36% of the Chihuahua state. The population density in the city is 5,600 inhabitants per km^2. One of the main characteristics of Ciudad Juárez is the migratory flow across the border, mainly due to the increasing maquiladora industry. Between 1950 and 1990, the population increased six-fold (2).

3.1 Study population

The base population of the study corresponded to the urban population of children in Ciudad Juárez exposed to air pollution levels considered hazardous to health. This population in Mexico is increasing given the large migration from rural to urban areas and because of high fertility rates. For this project, we focused our analysis on children's population subgroups, which are considered to be more susceptible to the effects of air pollution, such as young children (<1 year and 1 to 5 years) and children living in different conditions, as defined by the socio-economic status (SES) index. We included data from 1997 until 2001.

3.2 Health impact assessment

We used data of mortality and emergency visits for respiratory-related causes as health outcomes. Morbidity data were further stratified by specific respiratory illnesses including upper respiratory illnesses, lower respiratory illnesses and asthma. Health data were linked to ambient air pollution and climatic data obtained through the monitoring networks of Ciudad Juárez and El Paso.

3.2.1 Health database development

3.2.1.1 Mortality data: Death certificates

We obtained mortality certificates for children 0 to 16 years from 1997 to 2001 from the Health Ministry of Chihuahua. Information from the death certificates was captured in a database, including the following variables:

- Birth date
- Nationality
- Gender

- Address
- Age at death
- Place of death
- Primary, secondary and tertiary causes of death
- Duration of illness prior to death

Death certificates do not provide information on SES. We assigned an SES index to each child based on the zip code of his or her residency using a database developed by the municipality of Ciudad Juárez. To develop this index, the municipality of Ciudad Juárez used the prevalence and kinds of public services available (means of having access to water, to electricity, and types of roads and other general services provided by the municipality) (3) and defined SES indices for different areas of the city.

We assigned five different SES levels that were used to determine if SES levels modified the effect of ambient air pollutant on mortality. Mortality data were further stratified by age group (<=1 month, 1 month to 1 year, 1 to 5 years, >5 years).

3.2.1.2 Morbidity data: Data on emergency visits

We contacted different health units pertaining to the most important health care system in Mexico (Instituto Mexicano del Seguro Social (IMSS)) providing services for the working population of Mexico, consisting of approximately 70% of the total Mexican population. Our choice was based on the fact that this institution has a defined base population, corresponding to workers assigned to this system and keeps track of services provided in a systematic manner.

Ciudad Juárez included 11 IMSS family practice clinics that refer all emergency visits to two major second-level health care hospitals (IMSS # 35 and IMSS # 6). From these hospitals, we obtained data for the following time periods:

June 1997	to	December 1998 for both hospitals;
March 1999	to	September 1999 for IMSS #35;
November 1999	to	December 1999 for IMSS #35;
January 1999	to	November 1999 for IMSS #6 (excluding April and August);
May 2000	to	December 2000 for IMSS #35;
January 2000	to	December 2000 for IMSS #6;
January 2001	to	December 2001 for IMSS #35 (excluding June and July);
January 2001	to	November 2001 for IMSS #6 (excluding June and July).

Data from IMSS #35 and IMSS #6 hospitals (for different periods from June 1997 until December 2001) were assembled. However, because the IMSS does not maintain an electronic backup for a period of more than six-months, we could not access some of the information that had been deleted from the system but we could recuperate information from stored written records.

To develop the database, the following steps were necessary:

1. To obtain the database for 1997–98 used previously for the elaboration of a master's thesis at the INSP (3).
2. To check IMSS backup files from 1999–2000.
3. To obtain recent data for each unit through the clinical archive department.
4. To validate morbidity data (emergency room visits).

Respiratory-related emergency visits were further stratified in emergency visits for upper respiratory illnesses, lower respiratory illnesses, and asthma, and by age groups (<1, 1 to 5 years and >5 years).

3.2.2 Exposure database development

3.2.2.1 Sources of air pollution data

Air pollution data were obtained from the Ciudad Juárez monitoring network system. The system has five fixed monitoring stations distributed throughout Ciudad Juárez. The quality of the data is audited through the national program conducted by the Instituto Nacional de Ecologia (INE). All the stations measure daily PM_{10} every six days and three stations measure ozone. We also obtained climatic and meteorological variables (temperature, relative humidity and wind direction).

In addition, we obtained air pollution data from four monitoring stations located in El Paso close to the US-Mexico border. Two stations measure PM_{10} on a daily basis and one station measures ozone, NO_2, SO_2 and temperature.

Because PM_{10} levels are measured only every six days in Ciudad Juárez, we used a daily average of PM_{10} levels over the entire El-Paso/Ciudad Juárez air shed. Correlation analyses have shown significant relationships of the data over the different monitors (r=0.72). Figure 1 presents a map of Ciudad Juárez with the location of monitoring stations and the IMSS hospitals.

3.2.2.2 Preparation of databases

Air pollution data provided by Governmental Monitoring Network System were in a format that was not readily usable for analysis. Air pollution data sets were obtained for PM_{10}, ozone, temperature, and relative humidity (RH). We had a total of 720 separate data sets, which were checked for consistency and accuracy before being used in our analysis. When we found problems with the reported levels (such as close numbers without separation), data were checked and corrected if necessary. We then transformed the original databases in order to generate data sets for each pollutant and meteorological variables per year (1997, 1998, 1999, 2000, and 2001).

We estimated exposure indices for each pollutant, including the 24-hr average for PM_{10}, daily maximum of 8-hr mobile average and 1-hr maximum for ozone, yearly averages for both PM_{10} and ozone, and daily and yearly minimum and maximum temperature and relative humidity (RH). Data sets were finally used in Stata format (4).

3.2.3 Statistical analyses

We used a descriptive analysis for air pollution, climatic variables, and health data using frequency distribution and time-series plots of the raw data for quality control purposes. This also checked for unexplained extreme outlying values, for missing data, and for sudden changes in day-to-day variation in the series that are indicative of possible errors.

3.2.3.1 Mortality

We modeled the acute effects of air pollution on daily mortality as a function of the pollution levels on the same and preceding days and over 3, 5 and 7-day average air pollutant levels prior to the death date. We used an ambi-directional case-crossover approach. The case-crossover design controls many time-varying confounders by creating risk sets separated by only small intervals of time. Factors that vary over a longer time scale, such as year or season, or exposure to passive smoking, are the same. Weather factors, such as temperature, may co-vary on the same time scale as air pollution and so must be considered in the analysis. However, because the reference period is so close to the case periods, the variation in weather is less than that in the time series analysis and, hence, easier to model (5).

Air pollution levels on the dates of death were compared with air pollution levels during other weeks, but on the same day of the week as the death, and risk sets were defined (one case and eight control days). For example, if the death had occurred on a Monday, the previous Monday and the four following Mondays were selected as control days (6). The underlying hypothesis was that air pollution on the date of the death would be higher than those on control dates. We chose control days close to the date of death to assure that the season and day of the week would be controlled for, and use both pre and post-event control periods to assure control for time trends (6). Case-crossover avoids all confounding related to fixed characteristics of the individual, since a person is his own control. Variables related to the individual could act as effect modifiers, which we assessed with stratified analysis and determined by testing significance of the interaction term in the conditional logistic regression.

We estimate the association of respiratory mortality and air pollution levels using conditional logistic regression models with further adjustment for the year of the study and time. We considered that deaths occurring between birth and one month of age were unlikely to be related to air pollution exposure and therefore included the following age groups in the analysis: 1 month to 1 year, 1 year to 5 years and more than 5 years. Data were further stratified by socio-economic index to determine the presence of effect modification and an interaction term between SES and air pollutant variables to test for significance. Data were also analyzed after stratification of the data by age groups. Coefficients of the logistic regression models were exponentiated to estimate the percent increase in risk of death related to a 20 ppb increase in ozone ambient levels (1-hr maximum and maximum of 8-hr moving average) and 20 $\mu g/m^3$ in PM_{10} ambient levels (24-hr average).

3.2.3.1 Morbidity

We used Poisson regression to model the number of daily respiratory-related emergency visits in relation to ambient air pollution levels and included as an offset the total number of emergency visits (for any cause), therefore modeling for each day the proportion of respiratory-related emergency visits in relation to the total number of visits on that day. This allows adjusting for the fact that our base population might have changed over time given the significant migration to Ciudad Juárez during the study period. Data were fitted through the Generalized Additive Model (GAM), including smoothing functions for minimum temperature and relative humidity and time, using span equal to 0.01 (7). We also tested different span and maximum number of iterations than the one selected by our statistical program (S-Plus) but estimates of the effect of air pollution on emergency visits were unchanged. GAM provides a more flexible approach to model air pollution than fully parametric alternatives and have been widely used in time-series analyses of the linkage between air pollution and health. The GAM extends traditional generalized linear models by replacing linear predictors of the form $\eta = \Sigma_j \Sigma \beta_j \chi_j$ with $\eta = \Sigma_j f_j(\chi_j)$, where $f_j(\chi_j)$ are unspecified non-parametric functions. Unlike linear regression models, which are fitted by using weighted least squares and have an exact solution, the estimation procedure for a GAM requires iterative approximations in order to find optimal estimates (7). In addition to the non-parametric smoothing functions for temperature, humidity and time, our model adjusted for weekday and weekend-days, season, and year of the study (see Figure 2 for an example of residual from our GAM models)

We first evaluated the effect of individual pollutants, ozone and PM_{10}, with lag from one to four days and cumulative exposure (calculated as the average over several days) of three, five and seven days prior to the event. We then evaluated the effect of two pollutants, including ozone and PM_{10}, in the same model. Analyses were conducted using as outcome variables: total respiratory-related emergency visits, and separately for emergency visits for upper respiratory illnesses, lower respiratory illnesses, and asthma. The analysis was also stratified by age group (<1 years, 1 to 5 years, and >5 years to 16 years). Because we did not have information on the primary health clinics where the children were assigned to, we used the SES strata of the area where the IMSS hospitals were located and did a stratified analysis by hospital to determine the presence of heterogeneity in the results.

4 Results

4.1 Descriptive results

4.1.1 Mortality data

Mortality data are shown in Tables 1 to 3 by year of death, age group, gender, and cause of death. The highest mortality was observed in children of less than or equal to 1 month. Twenty percent of the total number of deaths was observed in children from 1 month to 1 year of age. The proportion of deaths was similar in both males and females. More than half of the death population (64.4%) was less than 1 month of age at date of death and 81% of these deaths were related to a respiratory cause. Among children between 1 month and 1 year of age, 33.2% were related to a respiratory cause. This proportion was 10% among older children (>5 years). Higher mortality was observed in children from low and middle-low socio-economic status (SES) as compared to middle-high and high SES (Table 4).

4.1.2 Morbidity data

Tables 5 through 7 present data on emergency-room visits in children less than 5 years of age. A total of 78,330 emergency visits were observed during the five-year period. Among them 57% were respiratory-related. Table 5 shows emergency visits by cause and specific diagnosis. The most important cause of emergency visits was upper airway respiratory infection (URI) with a percentage of 24.2%. Lower airway respiratory infections (LRI) were more frequent in the younger age groups (0 to 5 years), which were present by between 37% (of children <1 year) and 29.5% (of children between 1 and 5 years) (table 7).

4.1.3 Air pollutants and climatic variables

Tables 8 through 10 present the descriptive statistics of PM_{10} ambient levels during the study period in Ciudad Juárez and El Paso. We observed an increase in the 24-hr PM_{10} average between 1997 and 2001 in all monitoring stations of Ciudad Juárez except the station Pesta. The largest increases were observed in the stations M63 and M64 with yearly averages largely exceeding the standard of 50 $\mu g/m^3$ (Table 8). These two monitoring stations are located in the southern part of Ciudad Juárez close to roads with heavy traffic and might not represent the exposure of children attending the IMSS hospitals located in the northern part of the city, given that the dominant wind pattern in Ciudad Juárez comes from the northwest. The three other stations (M61, 62 and 66) might provide a better estimation. Table 9 presents PM_{10} ambient levels in El Paso. No substantial change was observed during the study period. Table 10 presents the yearly average levels of PM_{10} over the Ciudad Juárez and El Paso air shed. PM_{10} levels exceeded the norm only on a few occasions. Descriptive statistics showed that the annual averages of PM_{10} levels were higher in Ciudad Juárez than in El Paso.

Ozone data were obtained from three monitoring stations in Ciudad Juárez and levels were uniformly distributed over the city. Ozone levels exceeded the norm only on a few occasions (Table 11). Tables 12 and 13 present the yearly average of minimum temperature and relative humidity during the study period. Ozone was positively related to minimum temperature (r=0.46) while PM_{10} was not related to temperature. Ozone and PM_{10} were not related (r=0.01).

4.2 Associations between ambient air pollutants and health

Figures 3 through 5 show the time series for morbidity, air pollutant levels and minimum temperature during the study period (1997–2001). The morbidity time series suggest the presence of a seasonal component, whereas the daily count of deaths has many data points equal to zero, and there was only one day where six cases were reported with respiratory disease as the cause of children’s death.

4.2.1 Mortality

4.2.1.1 Health effects of ozone

Ozone ambient levels were not related to respiratory mortality in our population. We explored different lags and ozone levels over several days prior to death using a crossover approach, however no association was observed (Table 14). Because in our population the number of deaths for respiratory causes was small, we could only estimate the impact of ozone exposure on all children and on infants 0 to 1 year (Table 16) and on those of 1 month to 1 year (Table 17). Ozone ambient levels were not related to total mortality. However, for some estimates of ozone exposure, a negative association was observed between ozone and respiratory mortality. This is unlikely to represent a real effect and might suggest that ozone might be correlated with an unknown protector factor on mortality. In multipollutant models, including PM_{10} as well as ozone, none of the pollutants was related to mortality. When data were stratified by our index of socio-economic status, results were essentially null. No association was observed in either age group (Tables 18 and 19).

4.2.1.2 Health effects of PM_{10}

PM_{10} ambient levels were not related to the risk of dying from respiratory causes in all age groups. We explored different lags and PM_{10} levels over several days prior to death using a crossover approach, however no association was observed (Table 15). Among infants, we observed an increase in total mortality associated with five days cumulative average of PM_{10} (Table 17). When data were stratified by SES, an increase in respiratory mortality was also observed in the lowest SES group (Tables 20 and 21). Among infants 1 month to 1 year of age, a 20 $\mu g/m^3$ increase in PM_{10} 24-hr average on the previous day was associated with a 62% increase in respiratory mortality (95% CI 10% to 140%). When an increase of 20 $\mu g/m^3$ was observed on the two previous days, the risk of death was increased by 82% (95% CI 1% to 228%). These results remained similar in multipollutant models including ozone as well as PM_{10}. However, these results were based only on 41 deaths.

4.2.2 Morbidity

4.2.2.1 Health effects of ozone

Table 22 presents the association between ozone ambient levels (1-hr daily maximum and maximum of daily 8-hr mobile average) and respiratory-related emergency visits for all children (0 to 16 years). Results for three lags (1, 2, 3) and average ozone levels over three, five and seven days prior to the child's visit are presented. Coefficients were multiplied by 20 ppb corresponding to the interquartile range of the ozone levels during the study.

For both indexes of ozone exposure, ozone was related to the risk of respiratory-related emergency visits with a larger effect observed with a three-day lag (5.1% 95% CI 2.1% to 8.5% for an increase of 20 ppb in 1-hr maximum). Considering exposure over several days, the larger effect was observed for an increase of 20 ppb in 1-hr maximum ozone levels over seven days (15% 95% CI 6.4% to 24%). Similar results were observed when specific diagnoses were considered for upper respiratory infections (URI). We did not observe a significant effect from ozone ambient levels on the risk of lower respiratory illnesses. In contrast, ozone ambient levels were associated with asthma-related emergency visits. The largest effect was observed for a 1-

day lag (increase in risk of 8.3% 95% CI3.8% to 13.1%) and with an increase of ozone levels over several days (increase of 27.1% 95% CI 15.3% to 40.2% for an increase of 20 ppb 1-hr maximum over seven days prior to the visit).

These results were obtained with GAM models in which the ozone level was fitted without smoothing. When we fitted a model including a smoothing function for ozone (as well as for temperature and relative humidity), we observed that the relation between ozone ambient levels and respiratory-related emergency visits was almost linear between x and y and that the slope tended to level off at a cut-off point of approximately 130 ppb, suggesting that for extrapolation of the effect, at least two different coefficients should be considered depending on the levels of ambient ozone.

Table 23 presents results of the association between ozone ambient levels and respiratory-related emergency visits in children five years or younger. As for the total sample of children, ozone levels were related to total respiratory-related emergency visits, emergency visits for upper respiratory infection, and asthma. However, the increase in risk for children five years or younger was larger than in the total sample, suggesting that this group of children might be more susceptible to the impact of ozone. In addition, there was some suggestion that ozone ambient levels were positively associated with lower respiratory infections. We observed that an increment of 20 ppb in the maximum 8-hr moving average four days prior to the visit was related to a 12.7% increase in the risk of LRI (95% CI 4.2% to 21.9%). Considering an increase of 20 ppb in 1-hr daily maximum over five days prior to the visit, the risk was 15% (95% CI 2.3% to 29.4%).

Table 24 presents results of the association between ozone ambient levels and respiratory-related emergency visits in children between 6 and 16 years of age. In this age group, results were very similar to that observed in the total sample. Ozone ambient levels were significantly related to emergency visits for upper respiratory infection and asthma. In this age group, the largest effect was observed with a 1-day lag. An increase of 20 ppb in 1-hr maximum daily ozone was related to a 17.4% (95% CI 8.5% to 26.9%) increase in the risk of emergency visit for asthma and an increase of 20 ppb in the 8-hr maximum moving average was related to a 34.4% increase (95% CI 14.9% to 57.3%). An increase in ozone levels over several days was also related to an increase of asthma-related emergency visits (increase of 37.7% 95% CI 13.2% to 67.5% for an increase of 20 ppb of 1-hr maximum daily ozone over seven days prior to the visit).

4.2.2.2 Health effects of PM_{10}

Tables 25 through 27 present results of the association between PM_{10} ambient levels and respiratory-related emergency visits in all children. Relative risks are presented for an increase of 20 µg/m^3 in the 24-hr average of PM_{10}, corresponding to the interquartile range over the study period. We did not observe significant association between PM_{10} ambient levels and respiratory-related emergency visits, globally or after stratification by type of respiratory illness. Similar results were observed among children of five years and younger and children from 6 to 16 years of age. Among younger children, average PM_{10} levels over several days were unexpectedly negatively related to the risk of lower respiratory infections.

5 Discussion

In this study that covers a period of five years (1997–2001), we observed significant associations between ozone ambient levels and respiratory-related emergency visits. These associations were present for upper respiratory infections and asthma in all age groups. However in children five years or less, ozone exposure was also related to lower respiratory infections with a four-day lag. No association was observed with PM_{10} ambient levels.

Ambient air pollutants were not related to respiratory deaths in our population. However, there was some suggestion that PM_{10} ambient levels might increase the risk of respiratory mortality among infants (>1 month to 1 year) in children from lower socio-economic status.

Our results are consistent with those of a previous study conducted in Ciudad Juárez in 1997–1998 (3). However, our study included a five-year period and therefore had more power to detect an association. In addition, we were able to stratify the analyses by age groups and to identify an effect of ozone exposure on lower respiratory infections among younger children (<=5 years). Few studies have focused on the impact of ambient air pollution and respiratory-related emergency visits in children. These have been reviewed recently (8). In a study conducted in Mexico City, Tellez-Rojo et al. reported an increase in emergency visits for URI during winter months of 9.9% (95% CI 7.0-12.9) for an increase of 50 ppb in ozone 1-hr maximum (9). In a study conducted in Santiago, Chile, Ilabaca et al. reported an increase in the risk of lower respiratory infections in children 0 to 14 years associated with PM_{10} and $PM_{2.5}$ (10). An association was also observed for other contaminants, in particular ozone on summer days. However, in this study, PM_{10} levels were several times higher than those observed in our study, while ozone in the summer months was very similar to levels observed in this study. In a study conducted in Sao Paulo, Brazil, Gouveia et al. reported an increase of 7.6% in the risk of hospital admission for respiratory disease associated with an increase of 60 ppb in ozone ambient levels (24-hr average), while a significant effect of PM_{10} on the risk of hospitalization for pneumonia was observed among children less than 1 year of age (11). Ozone levels were similar to those observed in our study, while PM_{10} levels were considerably higher. In a study conducted in Ontario, Canada, Burnett et al. reported an increase of 19.1% in the percentage admission for respiratory infection in children 0 to 1 year and of 4.4% in subjects 2 to 34 years of age with an increase of 50 ppb ozone (1-hr max) and 5.3 $\mu g/m^3$ sulfate (daily average) (12). More recently in a time-series over 14 years (1980–1994), these authors reported an increase of 35% in hospitalization for respiratory problems in children of less than 2 years associated with an increase of 45 ppb in the 5-day moving average of 1-hr maximum ozone concentrations (13). In a study conducted in 25 hospitals of Montreal, Canada, Delfino et al. reported a 21% (95% CI 8 to 34%) increase in respiratory-related emergency visits in patients over 64 years of age related to an increase in the mean level of 1-hr maximum ozone (36 ppb). Among children of less than two years, a 5% increase was observed for an increase of 4.0nml H^+ (14). Based on these results and results from our study, it is clear that ozone ambient levels are a threat for the respiratory health of children. The current ozone standard in Mexico is 110 ppb 1-hr maximum, however, this standard was exceeded only on 14 days during our study period. This suggests that lower levels of ozone affect children's respiratory health and that action should be taken to decrease these levels.

We did not observe a significant impact of PM_{10} on respiratory-related emergency visits in our population. However, PM_{10} levels have been related to an increase of emergency visits and hospitalization mainly among the elderly with prior cardiovascular impairment (15), and few studies have observed an effect in children population (8), and none at levels of PM_{10} observed in our study.

Overall, none of the contaminants was associated with an increase in risk of mortality. However, when considering specific subgroups, we observed an adverse effect of PM_{10} in infants from lower SES, corresponding approximately to an increase of 2.5% in mortality with an increase of 10 $\mu g/m^3$ on the two days preceding death. Particulate matter has been associated with mortality in many studies (15-17). In a recent meta-analysis, Stieb et al. provide a comprehensive systematic synthesis of daily time-series studies of air pollution and mortality around the world, which reported an increase of 2.0% per 31.3 $\mu g/m^3$ in PM_{10}. Although a significant effect was also observed for ozone ambient levels, it did not persist in the multipollutant models (18). However, most of the study focused on the adult and elderly population. Very few studies have reported an increased relationship between air pollutants and mortality in children and the overall estimate of these studies support a non-significant effect (8). Loomis et al. reported a strong association between infant mortality and PM_{10} ambient levels. An increase of 10 $\mu g/m^3$ in PM_{10} ambient levels over three days was related to an increase of 6.9% in infant mortality with a 3-day lag. Infant mortality was also associated with ozone and NO_2 but not as consistently as with particles (19). In the study by Loomis et al., PM_{10} and ozone ambient levels exceeded largely those observed in our study. Gouveia et al. (20) also reported an increased risk of mortality for pneumonia in children less than five years related to PM_{10} and ozone but none of these estimates were statistically significant. In this study, PM_{10} was related to an increase of mortality in the elderly and a higher effect was observed among subjects from higher SES. However, none of these studies have looked at the potential modifying effect of SES on infant mortality. Our classification of SES was based on access to urban services and provides a reasonable classification of infants living conditions. When we considered infants in poorer living conditions, excluding infants of less than one month, given that most of the deaths in the perinatal period are very likely related to adverse pregnancy or delivery outcomes, we observed an increased risk of mortality. This suggests that these children are more susceptible to the adverse effects of particulate matter because of exposure to other environmental factors that might decrease their immune responses, such as micronutrient deficiencies and concurrent illnesses.

Several issues need to be discussed in the interpretation of our results. Particulate matter (PM_{10}) was measured only every six days in Ciudad Juárez. This is the reason why we also used data from El Paso, Texas, in order to obtain daily PM_{10} levels. However, the correlation between Ciudad Juárez and El Paso PM_{10} levels was high (r=0.72). We could not obtain a complete data set of emergency visits for all the five-year period, as mentioned earlier, but it is unlikely that different results would have been obtained if data in these missing months had been included in the analysis. In addition, some of the records did not have information on the date of the visit and could not be included in the analysis. It is also unlikely that this missing information be more or less common for respiratory-related emergency visits than for other types of emergency visits. It is also important to mention that the populations of children that we studied in our morbidity and mortality studies are not fully comparable. In the morbidity study, we included children having access to the IMSS health care system (workers social security) because of the availability of the medical records. In the mortality study, all deaths of children from Ciudad Juárez were included, covering therefore a larger socio-economic spectrum, in particular including children with health coverage from the Ministry of Health (SAS) that is offered to the poorest. This might explain in part some inconsistency between the morbidity and mortality results. Particulate appears to have an adverse effect, in particular in children that are already susceptible and at higher risk from other environmental exposure, while ozone seems to act as an irritant among all children, in particular among younger children and children with asthma.

6 Conclusion

In this report we present data on the impact of air pollutants on children's respiratory health from a city located on the US-Mexico border. This city is representative of many US-Mexico border cities with a growing population and poor environmental conditions and may also be representative of other urban populations in Mexico and other Latin American Countries. In addition, the air pollution levels observed in the study are commonly observed in many urban areas in the region. We observed an adverse effect of ozone ambient levels on emergency-visits for respiratory illnesses. The amplitude of the risk is quite significant and might represent a substantial cost to the health system and society in general. In addition, among the poorest population, particulate exposure was related to an increase in infant mortality implying a still greater impact on society.

Mexico, as in other developing countries, has a large urban population of children who live in poor conditions. Children, in particular, young children, are a sector of the population susceptible to environmental threats because of their behavior and a reduced capacity to metabolize toxic substances (21). In addition to physiologic vulnerabilities, many children in Latin America have great social vulnerabilities related to poverty, malnutrition, and poor environment that both increase their exposure to contaminants and their susceptibility to the effects of contaminants (22). Therefore, our results emphasize the need to implement cost-effective interventions to control existing air pollution problems and prevent the existing situation from worsening. It is clear that this will need the participation and determination of governments and civil society as a whole, at regional, national and local levels.

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Tables

Table 1. Mortality in children residing in Ciudad Juárez from 1997 to 2001, by year of death

Age group	1997	1998	1999	2000	2001	Total
<=1 month	415	397	471	438	435	2156
%	71.31	66.72	68.86	60.08	57.62	64.47
1m to 1yr	130	94	123	175	174	696
%	22.38	15.80	17.98	24.01	23.05	20.81
>1 to 5 yrs	36	41	31	42	44	194
%	6.20	6.89	4.53	5.76	5.83	5.80
>5 yrs	0	63	59	74	102	298
%	0.00	10.59	8.63	10.15	13.51	8.91
TOTAL	581	595	684	729	755	3344
%	100.00	100.00	100.00	100.00	100.00	100.00

Table 2. Mortality in children residing in Ciudad Juárez from 1997 to 2001, by gender

Age group	Male	Female	Total
<=1 month	64.26	64.56	64.38
1m to 1 yr	20.45	21.40	20.84
+1 to 5 yrs	5.41	6.26	5.76
>5 yrs	9.89	7.79	9.01

Table 3. Mortality in children residing in Ciudad Juárez from 1997 to 2001, by cause of death

Age group	Respiratory disease	Other	Total
<=1 month	1195	961	2156
%	81.02	51.42	64.48
1m to 1yr	231	465	696
%	15.66	24.88	20.81
>1 to 5 yrs	26	168	194
%	1.76	8.99	5.80
>5 yrs	23	275	298
%	1.56	14.71	8.91
TOTAL	1475	1869	3344
%	100.00	100.00	100.00

Table 4. Mortality in children residing in Ciudad Juárez from 1997 to 2000, by fringe index*

Age group	Low	Medium	High	Total
<=1 month	682	792	140	1614
%	(71.94)	(70.95)	(66.04)	(70.91)
1m to 1yr	159	210	41	410
%	(16.77)	(18.82)	(19.34)	(18.01)
>1 to 5 yrs	43	45	18	106
%	(4.54)	(4.03)	(8.49)	(4.66)
>5 yrs	64	69	13	146
%	(6.75)	(6.18)	(6.13)	(6.41)
TOTAL	948	1116	212	2276
%	(100.00)	(100.00)	(100.00)	(100.00)

* Some death certificates did not include place of death, which did not allow definition of the index. The highest level of the index could be considered as the lowest SES.

Table 5. Emergency visits for respiratory illnesses and other causes at IMSS # 6 and # 35, 1997–2001, Ciudad Juárez

Cause	n	%
Resp. Dis.	44699	57.06
Other	33631	42.94
Total	78330	100.00

Table 6. Emergency visits for respiratory illnesses, by type of diagnosis at IMSS #6 and #35, 1997–2001, Ciudad Juárez

Diagnosis	n	%
Acute nasopharyngitis	7841	17.54
Acute sinusitis	7	0.02
Acute pharyngitis	7184	16.07
Laryngitis and tracheitis	2611	5.84
URI*	10818	24.20
Bronchitis and bronchiolitis	9077	20.31
Pneumonia	2371	5.30
Asthma	4790	10.72
TOTAL	44699	100.00

*Upper Respiratory Infection

Table 7. Emergency visits for respiratory illnesses by age group and diagnosis at IMSS # 6 and # 35, 1997–2001 Ciudad Juárez

Age group	URI*	LRI**	Asthma	Total
< 1 year	8578 (30.14)	5389 (47.07)	659 (13.76)	14626 (32.72)
1-5 years	13858 (48.69)	5219 (45.59)	2384 (49.77)	21461 (48.01)
> 5 years	6025 (21.17)	840 (7.34)	1747 (36.47)	8612 (19.27)
Total	28461 (100.00)	11448 (100.00)	4790 (100.00)	44699 (100.00)

* URI = upper respiratory infection
** LRI = lower respiratory infection

Table 8. Annual average of PM_{10} levels, by monitor and year of the study (1997–2001), Ciudad Juárez

Monitoring stations	Year				
	1997	**1998**	**1999**	**2000**	**2001**
Advance (M64)					
Mean	89.66	71.25	99.89	106.73	108.37
Std. Dev.	54.87	30.66	48.13	60.55	76.87
Min.	12.70	16.40	23.94	16.02	17.86
Max.	312.00	154.30	207.60	348.06	324.44
Club 20/30 (M66)					
Mean	40.91	46.57	56.53	58.12	48.79
Std. Dev.	28.14	27.79	32.49	52.16	28.06
Min.	11.40	12.80	11.84	11.92	9.58
Max.	154.00	171.50	184.31	362.51	148.00
Pesta (M62)					
Mean	48.41	40.16	55.33	56.67	41.84
Std. Dev.	32.70	18.35	31.45	54.77	21.81
Min.	1.91	7.10	13.12	13.41	10.30
Max.	188.00	114.30	196.25	382.65	102.23
Tecno_1 (M61)					
Mean	30.66	37.73	49.69	41.37	39.88
Std. Dev.	11.93	9.82	23.44	24.30	17.82
Min.	9.46	26.70	16.63	8.63	11.64
Max.	60.80	53.50	109.20	138.96	79.84
Zenco (M63)					
Mean	69.59	59.72	76.74	88.74	97.38
Std. Dev.	53.09	64.10	39.56	51.40	59.79
Min.	13.70	10.10	18.08	22.79	13.97
Max.	309.00	196.60	156.93	278.62	356.29
Number of days over 150 $\mu g/m^3$	1	0	5	1	6
Number of days over 50 $\mu g/m^3$	45	52	102	84	56

Std. Dev. = Standard Deviation
PM_{10} concentration is in $\mu g/m^3$

Table 9. Annual average of PM_{10} levels, by year of the study (1997–2001) in El Paso, Texas

	Year				
	1997	1998	1999	2000	2001
PM_{10}					
Mean	30.08	33.00	40.66	40.08	33.327
Std. Dev.	17.86	15.51	27.85	19.47	23.08
Min.	6.49	6.80	5.00	6.00	7.00
Max.	149.00	120.60	213.00	145.50	182.00

Std. Dev. = Standard Deviation
PM_{10} concentration is in $\mu g/m^3$

Table 10. Annual average of PM_{10} levels, by year of study (1997–2001), averaging all monitors (Ciudad Juárez and El Paso)

	Year				
	1997	1998	1999	2000	2001
PM_{10}					
Mean	33.05	35.25	43.20	42.99	39.10
Std. Dev.	20.67	17.32	29.31	22.52	28.71
Min.	7.00	6.80	5.00	6.00	7.00
Max.	172.13	132.80	213.00	157.08	197.21
Number of days over 150 $\mu g/m^3$	1	0	5	1	6
Number of days over 50 $\mu g/m^3$	45	52	102	84	56

Std. Dev. = Standard Deviation
PM_{10} concentration is in $\mu g/m^3$

Table 11. Annual average of ozone, by monitor and year of study (1997–2001), Ciudad Juárez

Monitoring Stations	year				
	1997	1998	1999	2000	2001
Tecno_1 (M 61)					
Mean	27.05	31.76	30.40	30.12	32.60
Std. Dev.	20.84	20.62	19.06	19.20	19.79
Min.	1.00	1.00	1.00	1.00	1.00
Max.	138.00	186.00	288.00	131.00	126.00
Advance (M 64)					
Mean	29.64	32.70	24.43	23.63	29.84
Std. Dev.	16.70	18.80	19.11	16.99	15.40
Min.	2.00	1.00	1.00	1.00	1.00
Max.	92.00	114.00	338.00	88.00	102.00
Club 20/30 (M 66)					
Mean	23.44	25.73	30.61	30.40	31.11
Std. Dev.	18.80	18.10	19.29	20.03	20.01
Min.	1.00	1.00	4.00	1.00	1.00
Max.	148.00	262.00	104.00	131.00	141.00
Number of days over the norm (110 ppb)	1	1	5	6	1

Std. Dev. = Standard Deviation
Ozone concentration is in ppb

Table 12. Annual average of minimum temperature, by year of study (1997–2001), Ciudad Juárez

Minimum Temperature	Year				
	1997	1998	1999	2000	2001
Mean	18.77	14.43	15.08	15.97	15.82
Std. Dev.	8.64	6.48	6.18	6.27	6.74
Min.	-4.83	0	0	3.6	0.9
Max.	31.99	26.4	28.1	29.1	26.4

Table 13. Annual average of relative humidity, by year of study (1997–2001), Ciudad Juárez

Relative humidity	Year				
	1997	1998	1999	2000	2001
Mean	50.68	65.62	59.96	57.66	70.83
Std .Dev.	17.48	21.59	24.94	23.05	22.02
Min.	17.41	15.74	0.49	3.27	14.25
Max.	98	99.56	99.27	99.27	99.56

Table 14. Association between respiratory related mortality and O_3 ambient levels (1-hr max and 8-hr maximum moving average) in all children

Variables	OR*	95% CI	
O_3 1hr max lag1	1.020	0.950	1.094
O_3 8pm lag1	0.987	0.888	1.098
O_3 1hr max lag2	1.020	0.951	1.095
O_3 8pm lag2	1.021	0.917	1.138
O_3 1hr max lag3	0.948	0.883	1.018
O_3 8pm lag3	0.930	0.835	1.036
O_3 1hr max acd3	1.046	0.956	1.145
O_3 8pm acd3	1.034	0.910	1.176
O_3 1hr max acd5	0.996	0.898	1.105
O_3 8pm acd5	0.973	0.843	1.123
O_3 1hr max acd7	1.028	0.908	1.165
O_3 8pm acd7	0.988	0.836	1.168

*OR is calculated for an increase of 20 ppb of ozone

Table 15. Association between respiratory related mortality and PM_{10} ambient levels (24-hr average) in all children

Variables	OR*	95% CI	
PM_{10} lag1	1.020	0.970	1.074
PM_{10} lag2	1.002	0.948	1.059
PM_{10} lag3	1.012	0.958	1.069
PM_{10} ac2	1.041	0.966	1.121
PM_{10} ac3	1.035	0.920	1.164
PM_{10} ac5	1.028	0.879	1.203

*OR is calculated for an increase of 20 $\mu g/m^3$ of PM_{10} daily average.

Table 16. Association between total and respiratory-related mortality and PM_{10} (24-hr average) and ozone ambient levels in infants (0 to 1 year of age), 1997–2001, Ciudad Juárez

Variables	Total mortality			Respiratory mortality		
	OR*	95% CI		OR*	95% CI	
PM_{10} lag1	1.018	0.980	1.058	1.022	0.969	1.078
PM_{10} lag2	1.012	0.959	1.069	1.037	0.962	1.117
PM_{10} lag3	1.009	0.970	1.049	1.010	0.957	1.067
PM_{10} ac2	1.012	0.959	1.069	1.037	0.962	1.117
PM_{10} ac3	1.008	0.939	1.081	1.022	0.924	1.131
PM_{10} ac5	1.051	0.942	1.172	1.009	0.866	1.176
O_3 1hr max lag1	1.015	0.968	1.064	1.033	0.962	1.108
O_3 8pm lag1	1.004	0.930	1.084	1.013	0.911	1.126
O_3 1hr max lag2	1.000	0.949	1.053	1.013	0.944	1.087
O_3 8pm lag2	1.004	0.930	1.084	1.013	0.911	1.126
O_3 1hr max lag3	0.961	0.913	1.011	0.951	0.886	1.021
O_3 8pm lag3	0.933	0.864	1.007	0.931	0.837	1.035
O_3 1hr max acd2	1.018	0.956	1.084	1.041	0.962	1.126
O_3 8pm acd2	0.954	0.863	1.055	0.978	0.849	1.127
O_3 1hr max acd3	0.987	0.918	1.063	1.001	0.904	1.108
O_3 8pm acd3	0.954	0.863	1.055	0.978	0.849	1.127
O_3 1hr max acd5	0.976	0.892	1.066	1.026	0.909	1.159
O_3 8pm acd5	0.948	0.844	1.066	0.988	0.839	1.164

*OR is calculated for an increase of 20 $\mu g/m^3$ of PM_{10} daily average and 20 ppb in ozone indexes.

Table 17. Association between total and respiratory-related mortality and PM_{10} (24-hr average) and ozone ambient levels in infants (1 month to 1 year of age), 1997–2001, Ciudad Juárez

Variables	**Total mortality**			**Respiratory mortality**		
	OR	95% CI		OR	95% CI	
PM_{10}lag1	1.063	0.988	1.143	0.980	0.863	1.114
PM_{10}lag2	1.100	0.991	1.221	0.983	0.817	1.181
PM_{10} lag3	1.039	0.964	1.119	0.989	0.873	1.121
PM_{10}ac2	1.100	0.991	1.221	0.983	0.817	1.181
PM_{10}ac3	1.130	0.986	1.295	0.949	0.750	1.201
PM_{10} ac5	**1.283**	**1.030**	**1.598**	0.869	0.587	1.287
O_3 1hr max lag1	0.942	0.844	1.051	0.908	0.747	1.105
O_3 8pm lag1	0.916	0.777	1.080	0.791	0.587	1.066
O_3 1hr max lag2	0.984	0.880	1.100	0.809	0.647	1.011
O_3 8pm lag2	0.916	0.777	1.080	0.791	0.587	1.066
O_3 1hr max lag3	0.929	0.827	1.043	**0.787**	**0.629**	**0.984**
O_3 8pm lag3	0.912	0.771	1.080	0.779	0.576	1.053
O_3 1hr max acd2	0.936	0.816	1.074	0.791	0.604	1.036
O_3 8pm acd2	0.839	0.679	1.037	0.726	0.495	1.066
O_3 1hr max acd3	0.905	0.772	1.061	**0.702**	**0.519**	**0.949**
O_3 8pm acd3	0.839	0.679	1.037	0.726	0.495	1.066
O_3 1hr max acd5	0.866	0.715	1.048	**0.684**	**0.481**	**0.973**
O_3 8pm acd5	0.825	0.650	1.048	0.684	0.441	1.060

*OR is calculated for an increase of 20 $\mu g/m^3$ of PM_{10} daily average and 20 ppb in ozone indexes.

Table 18. Association between respiratory related mortality and ozone ambient levels among infants (0 to 1 year of age), according to SES index

Variables	SES 1*			SES 2*			SES 3*		
	OR+	95% CI		OR+	95% CI		OR+	95% CI	
O_3 1hr max lag1	1.020	0.907	1.148	0.978	0.863	1.109	1.033	0.820	1.301
O_3 8pm lag1	0.934	0.774	1.128	1.027	0.861	1.225	1.058	0.698	1.602
O_3 1hr max lag2	0.930	0.820	1.054	1.066	0.952	1.194	1.176	0.869	1.590
O_3 8pm lag2	0.912	0.759	1.096	1.072	0.893	1.287	1.271	0.826	1.957
O_3 1hr max lag3	1.033	0.918	1.161	0.961	0.854	1.081	0.888	0.660	1.194
O_3 8pm lag3	1.026	0.854	1.233	0.938	0.785	1.121	0.803	0.521	1.235
O_3 1hr max acd2	0.984	0.842	1.152	1.057	0.906	1.233	1.145	0.837	1.567
O_3 8pm acd2	0.942	0.756	1.173	1.055	0.852	1.307	1.259	0.768	2.063
O_3 1hr max acd3	1.001	0.835	1.202	1.008	0.846	1.201	1.078	0.735	1.581
O_3 8pm acd3	0.940	0.653	1.353	0.992	0.782	1.258	1.150	0.656	2.014
O_3 1hr max acd5	1.059	0.854	1.314	1.081	0.878	1.331	0.956	0.583	1.567
O_3 8pm acd5	0.989	0.743	1.317	1.075	0.817	1.414	0.980	0.499	1.924

*SES 1 = high SES 2 = medium SES 3 = low
OR+ is calculated for an increase of 20 ppb in ozone indexes.

Table 19. Association between respiratory related mortality and ozone ambient levels among infants (1 month to 1 year of age), according to SES index

Variables	SES 1*			SES 2*			SES 3*		
	OR+	95% CI		OR+	95% CI		OR+	95% CI	
O_3 1hr max lag1	1.178	0.751	1.849	0.713	0.463	1.098	1.210	0.717	2.042
$O_3$3 8pm lag1	1.041	0.535	2.027	0.717	0.414	1.242	0.670	0.215	2.089
O_3 1hr max lag2	0.670	0.424	1.060	0.839	0.569	1.235	0.839	0.332	2.115
O_3 8pm lag2	0.699	0.378	1.294	0.892	0.524	1.521	0.585	0.190	1.802
O_3 1hr max lag3	0.869	0.554	1.365	0.712	0.481	1.053	0.449	0.190	1.064
O_3 8pm lag3	0.792	0.423	1.483	0.631	0.372	1.072	0.334	0.106	1.048
O_3 1hr max acd2	0.836	0.483	1.447	0.698	0.427	1.139	1.150	0.507	2.610
O_3 8pm acd2	0.842	0.400	1.773	0.747	0.399	1.398	0.530	0.145	1.934
O_3 1hr max acd3	0.774	0.404	1.484	0.595	0.349	1.013	0.741	0.257	2.135
O_3 8pm acd3	0.771	0.339	1.756	0.624	0.320	1.215	0.340	0.083	1.382
O_3 1hr max acd5	0.742	0.339	1.626	0.575	0.313	1.055	0.458	0.132	1.594
O_3 8pm acd5	0.672	0.252	1.790	0.675	0.315	1.444	0.223	0.047	1.066

*SES 1 = high SES 2 = medium SES 3 = low
OR+ is calculated for an increase of 20 ppb in ozone indexes.

Table 20. Association between respiratory related mortality and PM_{10} ambient levels among infants (0 to 1 year of age), according to SES index

Variables	SES 1*			SES 2*			SES 3*		
	OR+	95% CI		OR+	95% CI		OR+	95% CI	
PM_{10} lag1	0.993	0.897	1.099	1.026	0.942	1.118	1.192	1.000	1.422
PM_{10} lag2	0.984	0.893	1.084	0.993	0.904	1.091	1.123	0.923	1.366
PM_{10} lag3	1.018	0.925	1.121	1.088	0.998	1.186	0.918	0.741	1.136
PM_{10} ac2	1.014	0.872	1.180	1.041	0.919	1.178	**1.377**	**1.047**	**1.812**
PM_{10} ac3	1.035	0.862	1.242	1.150	0.981	1.349	1.150	0.781	1.694
PM_{10} ac5	0.818	0.614	1.089	1.174	0.917	1.502	1.297	0.709	2.372

*SES 1 = high SES 2 = medium SES 3 = low
OR+ are calculated for an increase of 20 $\mu g/m^3$ of PM_{10} daily average

Table 21. Association between respiratory related mortality and PM_{10} ambient levels among infants (1month to 1 year of age), according to SES index

Variables	SES 1*			SES 2*			SES 3*		
	OR+	95% CI		OR+	95% CI		OR+	95% CI	
PM_{10} lag1	0.788	0.578	1.073	1.021	0.817	1.276	1.626	1.099	2.406
PM_{10} lag2	1.080	0.854	1.367	1.010	0.798	1.277	1.041	0.716	1.514
PM_{10} lag3	1.090	0.862	1.378	0.970	0.752	1.252	0.835	0.543	1.286
PM_{10} ac2	0.869	0.576	1.312	1.014	0.741	1.387	1.822	1.012	3.281
PM_{10} ac3	0.988	0.572	1.706	1.013	0.651	1.578	1.584	0.753	3.332
PM_{10} ac5	0.676	0.284	1.607	0.607	0.277	1.329	1.844	0.508	6.697

*SES 1 = high SES 2 = medium SES 3 = low
OR+ is calculated for an increase of 20 $\mu g/m^3$ of PM_{10} daily average

Table 22. Association between respiratory related emergency visits and ozone ambient levels (1-hr daily maximum and maximum daily 8-hr average) for total respiratory visits and upper respiratory infection (URI), lower respiratory infection (LRI), and asthma in children 0 to 16 years

Variables	TOTAL			URI			LRI			ASMA		
	RR	95%CI		RR	95% CI		RR	95% CI		RR	95% CI	
0_3 1hr max lag 1	1.04	1.009	1.074	1.041	1.005	1.078	0.980	0.928	1.035	1.083	1.038	1.131
0_3 8pm lag 1	1.062	1.021	1.104	1.085	1.027	1.147	0.905	0.840	0.975	1.212	0.553	2.654
0_3 1hr max lag 2	1.020	0.989	1.053	1.024	0.989	1.061	0.972	0.920	1.027	1.066	1.021	1.113
0_3 8pm lag 2	1.062	1.021	1.104	1.014	0.960	1.071	0.921	0.855	0.993	1.127	1.042	1.219
0_3 1hr max lag 3	1.051	1.021	1.085	1.062	1.025	1.100	1.008	0.954	1.065	1.051	1.003	1.102
0_3 8pm lag 3	1.041	1.001	1.082	1.060	1.003	1.119	0.942	0.871	1.019	1.103	1.020	1.193
0_3 1hr max lag 4	1.012	.981	1.044	1.010	0.975	1.046	0.998	0.948	1.050	1.030	0.983	1.080
0_3 8pm lag 4	1.018	.979	1.059	1.016	0.962	1.073	0.990	0.919	1.067	1.090	1.008	1.179
0_3 1hr max ac3d	1.083	1.042	1.127	1.116	1.061	1.175	0.963	0.887	1.045	1.174	1.094	1.259
0_3 8pm ac3d	1.062	.982	1.148	1.099	1.024	1.179	0.852	0.773	0.940	1.284	1.164	1.416
0_3 1hr max ac5d	1.127	1.042	1.219	1.150	1.080	1.225	1.016	0.925	1.116	1.246	1.143	1.358
0_3 8pm ac5d	1.105	1.022	1.195	1.127	1.038	1.224	0.936	0.839	1.045	1.350	1.205	1.512
0_3 1hr max ac7d	1.15	1.064	1.244	1.174	1.094	1.259	0.949	0.854	1.055	1.271	1.153	1.402
0_3 8pm ac7d	1.127	1.042	1.219	1.217	1.116	1.326	0.847	0.753	0.953	1.297	1.153	1.459

O_3 1hr max: 1-hr daily maximum
O_3 8pm: daily maximum 8-hr mobile average
RR = relative risk
95% CI = 95% Confidence Intervals

Table 23. Association between respiratory related emergency visits and ozone ambient levels (1-hr daily maximum and maximum daily 8-hr average) for total respiratory visits and upper respiratory infection (URI), lower respiratory infection (LRI), and asthma, in children five years or younger

Variables	TOTAL			URI			LRI			ASTHMA		
	RR	95% CI		RR	95% CI		RR	95% CI		RR	95% CI	
0_3 1hr max lag 1	1.026	0.979	1.076	1.041	1.001	1.082	0.988	0.914	1.069	1.105	1.022	1.195
0_3 8pm lag 1	1.018	0.949	1.093	1.083	1.002	1.172	0.905	0.820	0.998	1.083	0.926	1.267
0_3 1hr max lag 2	1.030	0.983	1.080	1.041	1.001	1.082	1.008	0.939	1.082	1.062	0.982	1.148
0_3 8pm lag 2	1.014	0.949	1.084	1.020	0.943	1.103	1.002	0.891	1.127	1.127	0.964	1.319
0_3 1hr max lag 3	1.062	1.021	1.104	1.083	1.042	1.127	1.062	0.982	1.148	1.083	1.002	1.172
0_3 8pm lag 3	1.041	0.970	1.117	1.062	0.982	1.148	1.006	0.909	1.114	1.127	0.964	1.319
0_3 1hr max lag 4	1.041	1.001	1.082	1.041	1.001	1.082	1.049	0.970	1.135	1.062	0.982	1.148
0_3 8pm lag 4	1.083	1.002	1.172	1.062	0.982	1.148	1.127	1.042	1.219	1.127	0.964	1.319
0_3 1hr max ac3d	1.099	1.024	1.179	1.127	1.042	1.219	1.016	0.903	1.143	1.221	1.086	1.374
0_3 8pm ac3d	1.026	0.934	1.128	1.083	0.963	1.218	0.887	0.758	1.037	1.323	1.088	1.610
0_3 1hr max ac5d	1.174	1.085	1.269	1.197	1.107	1.295	1.150	1.023	1.294	1.433	1.225	1.677
0_3 8pm ac5d	1.174	1.043	1.320	1.197	1.064	1.347	1.127	0.964	1.319	1.584	1.252	2.004
0_3 1hr max ac7d	1.197	1.107	1.295	1.221	1.086	1.374	1.041	0.890	1.218	1.462	1.202	1.779
0_3 8pm ac7d	1.221	1.086	1.374	1.323	1.176	1.488	0.994	0.817	1.209	1.616	1.277	2.045

O_3 1hr max: 1-hr daily maximum
O_3 8pm: daily maximum 8h mobile average
RR = relative risk
95% CI = 95% Confidence Intervals

Table 24. Association between respiratory related emergency visits and ozone ambient levels (1-hr daily maximum and maximum daily 8-hr average) for total respiratory visits and upper respiratory infection (URI), lower respiratory infection (LRI), and asthma, in children older than five years of age

Variables	TOTAL			URI			LRI			ASMA		
	RR	95% CI		RR	95% CI		RR	95% CI		RR	95% CI	
0_3 1hr max lag 1	1.105	1.022	1.195	1.083	1.013	1.158	1.008	0.862	1.179	1.174	1.085	1.269
0_3 8pm lag 1	1.174	1.085	1.269	1.150	1.023	1.294	1.062	0.839	1.343	1.344	1.149	1.573
0_3 1hr max lag 2	1.041	0.962	1.126	1.041	0.962	1.126	0.869	0.743	1.017	1.127	1.042	1.219
0_3 8pm lag 2	1.010	0.934	1.092	1.010	0.909	1.123	0.869	0.715	1.058	1.083	0.926	1.267
0_3 1hr max lag 3	1.024	0.962	1.091	1.041	0.962	1.126	1.006	0.860	1.177	0.972	0.865	1.094
0_3 8pm lag 3	0.996	0.921	1.077	0.992	0.892	1.103	0.967	0.764	1.223	1.010	0.863	1.182
0_3 1hr max lag 4	1.004	0.928	1.086	1.008	0.932	1.090	1.083	0.926	1.267	0.961	0.854	1.081
0_3 8pm lag 4	1.020	0.943	1.103	1.006	0.894	1.132	1.246	0.985	1.576	0.992	0.848	1.160
0_3 1hr max ac3d	1.150	1.064	1.244	1.174	1.043	1.320	0.869	0.687	1.100	1.246	1.065	1.458
0_3 8pm ac3d	1.127	1.002	1.268	1.150	0.983	1.346	0.856	0.650	1.126	1.271	1.045	1.547
0_3 1hr max ac5d	1.221	1.086	1.374	1.246	1.108	1.402	0.942	0.716	1.239	1.246	1.065	1.458
0_3 8pm ac5d	1.274	1.089	1.490	1.271	1.087	1.487	0.988	0.722	1.352	1.405	1.110	1.777
0_3 1hr max ac7d	1.323	1.176	1.488	1.350	1.154	1.579	0.923	0.649	1.314	1.377	1.132	1.675
0_3 8pm ac7d	1.492	1.275	1.745	1.553	1.276	1.889	1.018	0.688	1.507	1.433	1.089	1.886

O_3 1hr max: 1-hr daily maximum
O_3 8pm: daily maximum 8h mobile average
RR = relative risk
95% CI = 95% Confidence Intervals

Table 25. Association between respiratory related emergency visits and PM_{10} ambient levels (24-hr average) for total respiratory visits and upper respiratory infection (URI), lower respiratory infection (LRI), and asthma in all children

Variables	TOTAL			URI			LRI			ASMA		
	RR	95%CI		RR	95%CI		RR	95%CI		RR	95%CI	
PM_{10}lag 1	1.00	.977	1.024	1.000	0.973	1.028	1.000	0.731	1.368	1.020	0.981	1.061
PM_{10}lag 2	1.002	.979	1.026	1.006	0.979	1.034	0.990	0.696	1.409	1.014	0.987	1.042
PM_{10} lag 3	1.004	.981	1.028	1.002	0.975	1.030	1.010	0.979	1.042	1.002	0.963	1.042
PM_{10} lag 4	.996	.973	1.02	0.998	0.971	1.026	0.988	0.958	1.020	0.990	0.952	1.030
PM_{10} 3 d	1.006	.964	1.05	1.020	0.973	1.069	0.961	0.906	1.019	0.942	0.871	1.019
PM_{10} ac 5 d	1.018	.941	1.101	1.035	0.964	1.110	0.961	0.888	1.039	1.014	0.938	1.097
PM_{10} ac 7 d	1.020	.979	1.059	1.041	0.962	1.126	1.041	0.925	1.171	0.869	0.773	0.978

Table 26. Association between respiratory related emergency visits and PM_{10} ambient levels (24-hr average) for total respiratory visits and upper respiratory infection (URI), lower respiratory infection (LRI), and asthma in children five years or younger

Variables	TOTAL			URI			LRI			ASMA		
	RR	95%CI		RR	95%CI		RR	95%CI		RR	95%CI	
PM_{10} lag 1	0.992	0.961	1.024	0.984	0.950	1.019	1.004	0.965	1.044	1.012	0.936	1.095
PM_{10} lag 2	1.000	0.969	1.032	1.002	0.967	1.038	0.992	0.954	1.032	1.012	0.936	1.095
PM_{10} lag 3	1.004	0.973	1.036	1.006	0.971	1.042	1.014	0.975	1.055	0.923	0.854	0.998
PM_{10} lag 4	1.020	0.989	1.053	1.030	0.999	1.063	1.008	0.969	1.048	0.980	0.906	1.060
PM_{10} ac 3 d	0.980	0.906	1.060	1.004	0.928	1.086	0.923	0.854	0.998	0.980	0.871	1.103
PM_{10} ac 5 d	0.961	0.888	1.039	1.018	0.941	1.101	0.819	0.728	0.921	0.990	0.846	1.158
PM_{10} ac 7 d	0.923	0.821	1.038	0.998	0.887	1.123	0.819	0.700	0.958	0.942	0.716	1.239

Table 27. Association between respiratory related emergency visits and PM_{10} ambient levels (24-hr average) for total respiratory visits and upper respiratory infection (URI), lower respiratory infection (LRI), and asthma in children older than five years

Variables	TOTAL			URI			LRI			ASMA		
	RR	95%CI		RR	95%CI		RR	95%CI		RR	95%CI	
PM_{10} lag 1	0.982	0.944	1.021	0.961	0.924	0.999	0.984	0.896	1.081	1.020	0.943	1.103
PM_{10} lag 2	0.992	0.954	1.032	0.980	0.943	1.019	1.062	0.982	1.148	1.062	0.982	1.148
PM_{10} lag 3	1.016	0.977	1.057	1.000	0.954	1.048	1.016	0.940	1.099	1.062	0.982	1.148
PM_{10}lag 4	1.010	0.971	1.050	1.012	0.966	1.061	1.083	1.002	1.172	0.942	0.871	1.019
PM_{10} ac 3 d	1.004	0.928	1.086	0.835	0.772	0.903	1.002	0.857	1.172	1.041	0.925	1.171
PM_{10} ac 5 d	1.041	0.925	1.171	1.006	0.860	1.177	1.105	0.840	1.454	1.062	0.873	1.292
PM_{10} ac 7 d	1.006	0.860	1.177	1.012	0.832	1.231	1.174	0.825	1.670	0.980	0.745	1.290

Figure 1. IMSS units and fixed monitoring sites in study area, Ciudad Juárez, Chihuahua, Mexico

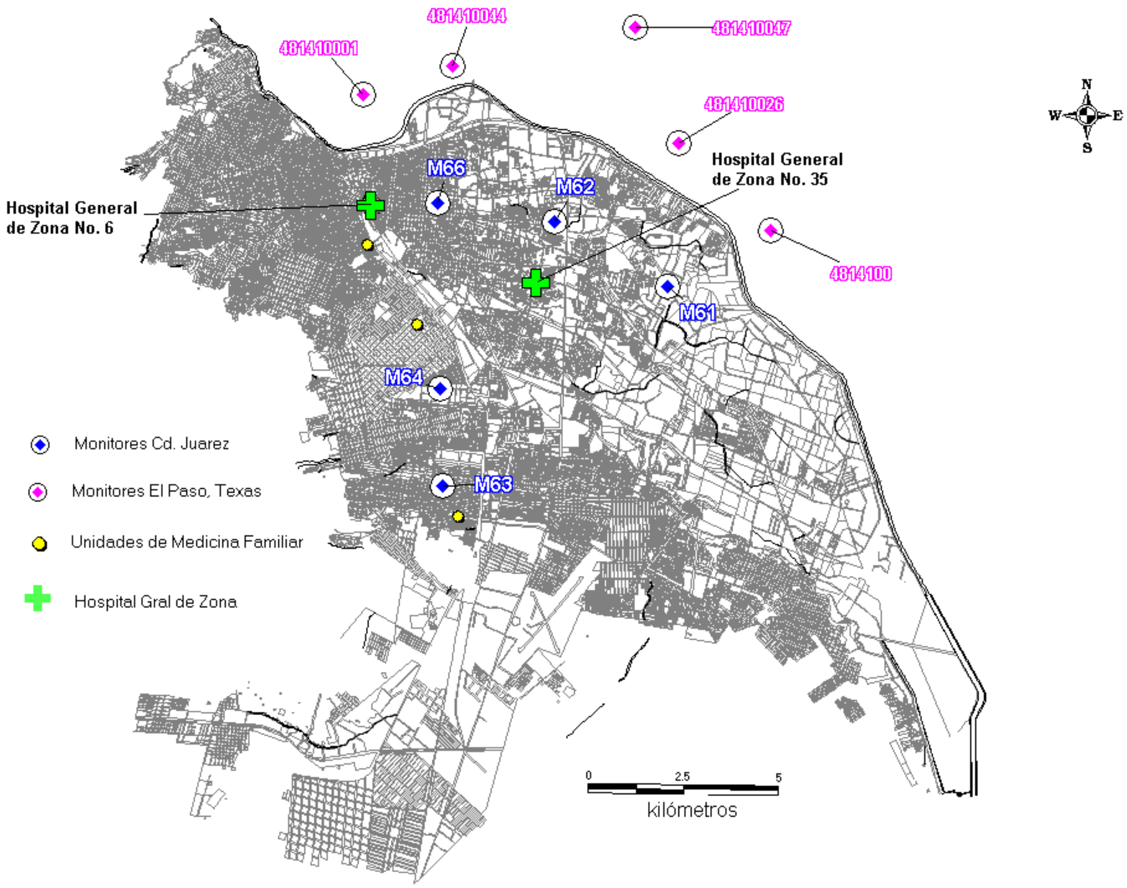

Figure 2. Example of residuals from GAM models

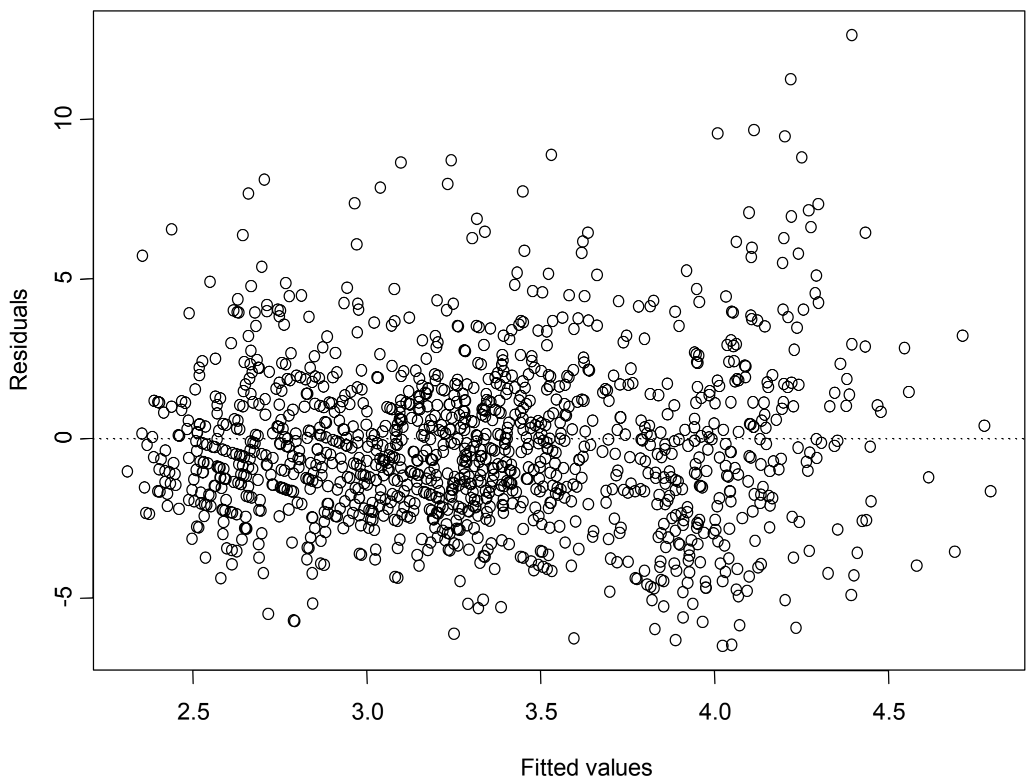

Figure 3. Morbidity, PM_{10} and temperature during the study, 1997-2001, Ciudad Juárez, Mexico

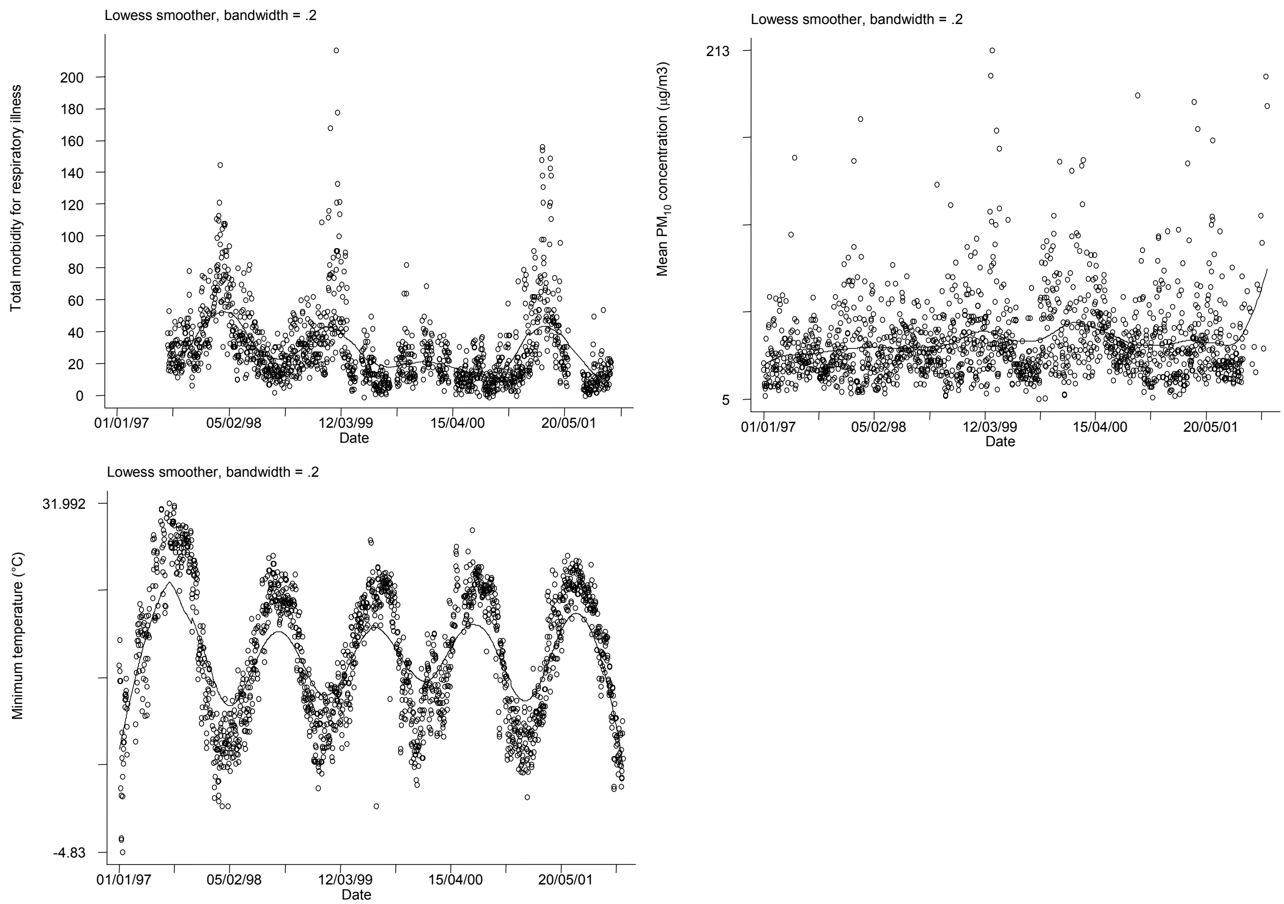

Figure 4. Ozone and temperature during the study period, 1997-2001, Ciudad Juárez, Mexico

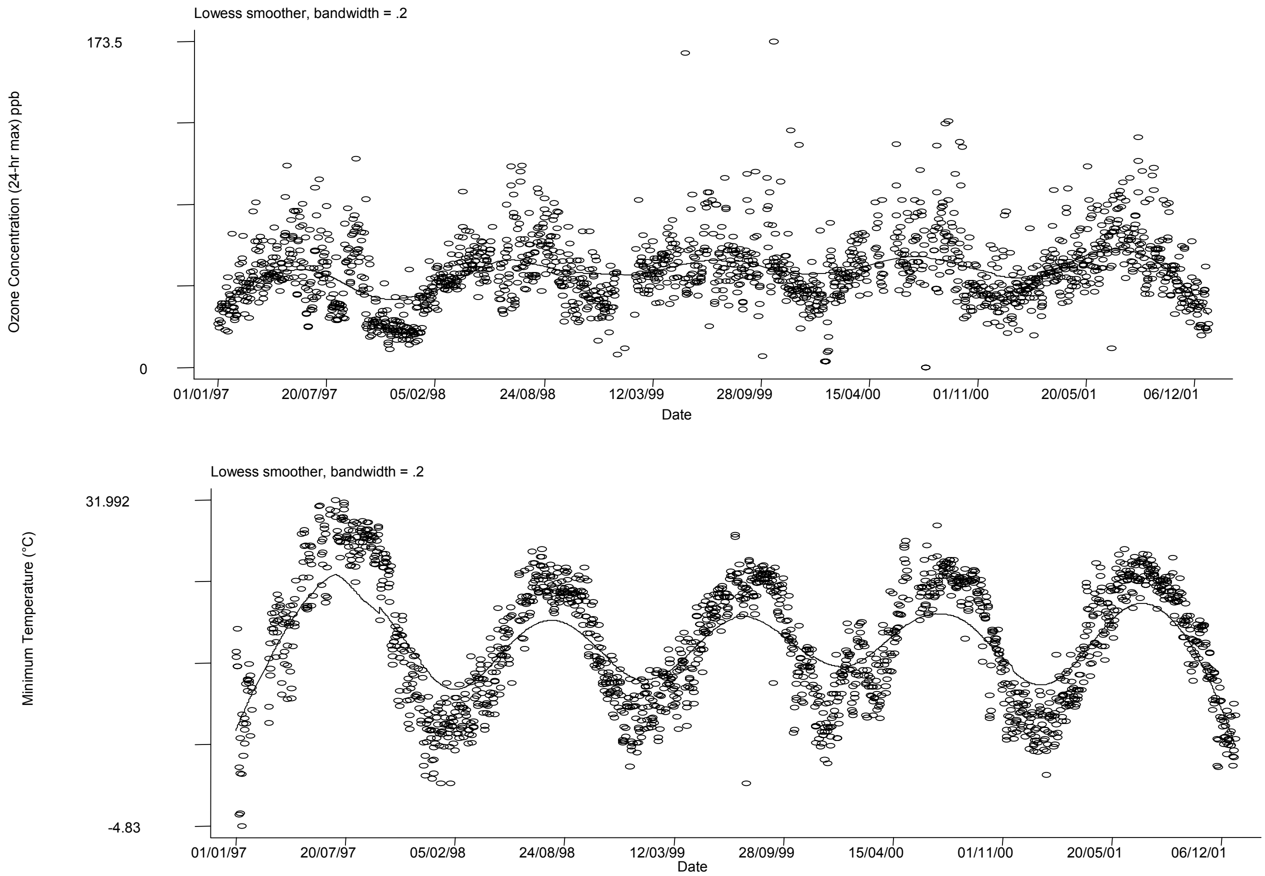

Figure 5. Morbidity and ozone during the study period, 1997-2001, Ciudad Juárez, Mexico