Revista Mexicana de Ingeniería Biomédica

Volumen *Volume* 26 Número *Number* 1 Marzo *March* 2005

Artículo:

Correlation Study of the Association of PM10 with the Main Respiratory Diseases in the Populations of Mexicali, Baja California and Imperial County, California

ARTÍCULO DE INVESTIGACIÓN ORIGINAL

REVISTA MEXICANA DE INGENIERÍA BIOMÉDICA
SOMIB
Vol. XXVI, Núm. 1
Marzo 2005
pp 22 - 36

Correlation Study of the Association of PM10 with the Main Respiratory Diseases in the Populations of Mexicali, Baja California and Imperial County, California

Marco Antonio Reyna Carranza,* Margarito Quintero Núñez,* Kimberly Collins**

* Instituto de Ingeniería de la Universidad Autónoma de Baja California. Mexicali, Baja California, México.

** California Center for Border and Regional Economic Studies (CCBRES), San Diego State University-I.V. Campus, Calexico, CA

Correspondence:
Marco Antonio Reyna Carranza.
Blvd. Benito Juárez y Calle de la Normal, Unidad Universitaria s/n, Col. Insurgentes-Este, C.P. 21280, Mexicali, Baja California, México,
E-mail: mreyna@uabc.mx,
Fax:+52 686 566-4150.
PO BOX Address: PMB 10241, 317 Heffernan Ave. Calexico, CA. 92231-2739

ABSTRACT

Mexicali is the third most contaminated city in Mexico and the second city in the country with the highest level of particles smaller than 10 micrometers in diameter (PM10). It continuously fails to meet annual air quality standards (50 $\mu g/m^3$). Mexicali's U.S. neighbor, the Imperial County, has the same geographical characteristics, and is in non-attainment for PM10, ozone, and carbon monoxide. One health condition associated with high PM10 levels is asthma and both Imperial Valley and Mexicali have the highest child asthma indices for their respective states of California and Baja California. PM10 is primarily formed naturally, from dust and pollen, but anthropogenic sources are gaining importance due to an accelerated growth in this bi-national basin. Thermoelectric plants recently constructed are an example of this accelerated growth and their construction prompts bi-national concern in a basin with an already deteriorated air quality. There are a limited number of published documents focusing on Mexicali's and Imperial County's health or environment. Only a few articles contain data on PM10 levels or respiratory illnesses (including asthma), and even less jointly report on health conditions and the environment. This lack of information has produced flawed and unproductive environmental policy in the U.S.-Mexican border region. A model based on the Poisson regression was used to study the impact PM10 may have had on primary respiratory diseases given the temperature and relative humidity in the Imperial Valley-Mexicali basin. The years 1997 to 2000 were measured in series by seasons. Air quality data, specifically PM10 data, were supplied by a regional network of air monitoring stations in the Imperial Valley and Mexicali. Health data, including asthma, acute respiratory infections, bronchitis, and pneumonia were obtained from Baja California public health centers and the California Office of Statewide Health Planning and Development, Healthcare Quality and Analysis Division.

Key Words:
PM10, Poisson, Mexicali-Imperial airshed, respiratory diseases, asthma, thermoelectric plants, air pollution.

RESUMEN

Mexicali es la tercera ciudad más contaminada de la República Mexicana en términos generales y la segunda más contaminada por micropartículas respirables menores a los diez micrómetros de diámetro (PM10). Los estándares de protección al ambiente (50 µg/m^3), son rebasados de manera continua durante prácticamente todo el año. La ciudad de Mexicali es vecina del Condado Imperial en los Estados Unidos de Norteamérica, y por lo tanto además de compartir las mismas condiciones geográficas, también comparten los mismos problemas de contaminación existentes en la cuenca atmosférica binacional. Los principales contaminantes que no cumplen con los estándares de calidad del aire son: PM10, Ozono (O_3), y Monóxido de Carbono (CO). Una de las principales enfermedades respiratorias asociadas a los altos niveles de PM10 es el asma. Mexicali y el Valle Imperial presentan los mayores índices de niños asmáticos dentro de sus respectivos estados (i.e., Baja California y California respectivamente). En esta región fronteriza, el PM10 tiene su origen principalmente por fuentes naturales, tales como polvo y polen, aunque las fuentes antropogénicas han ido en aumento dado el crecimiento tan acelerado de la cuenca binacional. Las plantas termoeléctricas recientemente construidas son un ejemplo de este crecimiento acelerado y su operación genera preocupación en la población binacional por las posibles consecuencias que esto conllevará en la ya de por sí deteriorada calidad del aire de la cuenca atmosférica fronteriza. Existen algunos documentos publicados en la literatura que tocan temas sobre salud o sobre contaminación de Mexicali o del Condado de Imperial, pero un número muy reducido de estos documentos reportan datos y mucho menos tratan problemas de contaminación y efectos en la salud de manera binacional. Esta carencia de información se traduce en diseño de políticas y lineamientos muy pobres en materia de salud y contaminación ambiental sobre esta tan descuidada zona fronteriza entre EUA y México. Se propone un modelo basado en la regresión de Poisson para estudiar el posible impacto que el PM10 pudiera tener sobre las principales enfermedades respiratorias, dadas las condiciones de temperatura y humedad relativa de la cuenca atmosférica entre Mexicali e Imperial. Fueron analizadas series de tiempo para los años de 1997 al 2000. Las series de tiempo de la calidad del aire, específicamente de PM10, fueron proporcionadas por una red de estaciones de monitoreo ambiental establecida en Mexicali e Imperial. Los datos de salud, los cuales incluyeron: asma, infecciones respiratorias agudas, bronquitis y neumonía se obtuvieron de los centros de salud públicos de Mexicali y de la *California Office of Statewide Health Planning and Development, Healthcare Quality and Analysis Division*.

Palabras clave:
PM10, Poisson, cuenca atmosférica Mexicali-Imperial, enfermedades respiratorias, asma, plantas termoeléctricas, contaminación del aire.

INTRODUCTION

The first evidence suggesting that air pollution was related to illness and death was recorded in England in 1880. It was in this year that a large, dark cloud appeared in the London sky and subsequently nearly 2,200 people died. Almost three-quarters of a century later, a similar situation occurred in the same city, in which 4,000 people died. This event is well known as the London Fog of 1952[1].

After these and numerous other comparable events took place, scientists became more involved in the study of air pollution and its effects on health. In the twenty-first century, the relationship between breathable suspended particles and mortality and morbidity has been further elucidated. The issue of environmental health has been gaining importance as a subject of profound interest throughout the world[2-8].

The most serious threats to the respiratory system are particulates that are suspended in the atmosphere for long periods of time at the height at which most people breathe. Perhaps the most dangerous of these materials is Total Suspended Particles (TSP). The particles in this classification that have the greatest impact on the respiratory system range from 10 microns in diameter (PM10) to smaller than 2.5 microns in diameter (PM2.5). The particles that measure between five and 10 microns do not reach the deepest tissues of the respiratory system because they are caught by mucous in the nose, larynx, pharynx, and trachea. Even though these particles are caught before reaching the depths of the respiratory system, they can still harmfully affect the body by inducing sneezing. If the sneezing becomes severe, it could lead to chronic illnesses such as otitis depending on the composition of the particles.

The smaller the diameter of the particle, the more harmful it becomes since these smaller particles are able to penetrate deeper areas of the respiratory track containing the internal tissues. Two of these areas, the bronchus and the alveolus, are particularly dangerous as reactions may take place that could bring about serious complications. These include: premature death, grave respiratory symptoms, irritation of the eyes, ears and nose, an increased risk of developing lung cancer, more acute asthma cases, and a worsening of cardiovascular diseases[9].

The suspended particles originate in either natural or anthropogenic sources. When they mix with the air, they become more complex. For larger particles with diameters between 2.5 and 10 microns, the principal sources of anthropogenic origination are factory smoke (such as cement kilns), dust from lime and other minerals, agricultural practices such as emissions from burning of agricultural residues and pesticide use, and dust from construction sites and unpaved streets. The majority of the naturally produced particles in this group come from pollen of several plants. The finest particles, those that measure less than 2.5 microns in diameter, come mainly from the emissions from fossil fuel combustion motors (such as those found in automobiles) and from nitrates and sulphates in the form of aerosols.

In order to prevent the harmful impacts of suspended particles on the health of the community, there are regulations that establish maximum permissible amounts in the concentration of particles in the air. Both the Mexican and U.S. regulatory standards for PM10 should not exceed 150 $\mu g/m^3$ (micrograms per cubic meter) for the 24 hour average and 50 $\mu g/m^3$ for the annual average.

BACKGROUND

The municipality of Mexicali, the capital of the state of Baja California, Mexico, is located in the farthest northwest state of the country. It shares the border with the Imperial County, CA in the United States. Imperial County is also known as the Imperial Valley. Mexicali and Imperial Valley share the same physical, geographical, and meteorological conditions. These common characteristics provide a situation in which contamination or pollution is shared through a binational airshed and watershed. For our purposes here, we will analyze the impacts of air pollution on the airshed. As seen in Table 1 both Mexicali and the Imperial Valley is non-attainment for PM10.

Table 1. Border Counties and Municipalities that do not meet U.S. and Mexico national air quality standards.

U.S. Counties	PM10	SO_2	CO	O_3
El Paso, TX	X		X	X
Doña Ana, NM	X			X
Imperial, CA	X		X	X
San Diego, CA			X	X
Douglas, AZ	X	X		
Nogales, AZ	X			
Mex. Municipalities				
Tijuana, BC	X			
Mexicali, BC	X		X	X
San Luis Río Colorado, SON	X			
Nogales, SON	X			
Agua Prieta, SON	X	X		
Ciudad Juárez, CHIH	X		X	X

Air pollution has been blamed for the high rates of asthma, bronchitis, pneumonia, and allergies in this region, especially among children between the ages of 1-14 years[10,11]. In fact, the rates of respiratory diseases have been worsening in both valleys as the concentrations of suspended micro particles continue to increase[12]. The Secretariat of the Environment and Natural Resources (SEMARNAT, formally known as SEMARNAP (Secretaría de Medio Ambiente, Recursos Naturales y Pesca)) in its second report classified Mexicali´s air quality as seriously dangerous (see Figure 1). Mexicali is the second city in the country after Mexico City that continuously exceeds the permitted annual averages of PM10 (150 $\mu g/m^3$)[13]. Additionally, the two newly constructed thermoelectric plants in Mexicali, La Rosita and La Termoeléctrica Mexicali, have created apprehensions that the air quality in the two valleys will diminish once the plants begin operations[14,15].

Interesting data on concentrations of various pollutants and respiratory diseases are found in Mexicali's emissions inventory[16], and in a presentation by IseSalud[11], at the *Forum on Environmental Health at the California-Baja California Border* that was held in Mexicali in April 2002[17]. The graphs of these reports show a systematic increase in respiratory diseases from 1998 to 2001.

In 1991, an article published in the Journal of Environmental Research[18] detailed the results of an analysis on the dust from Mexicali and from a series of experiments on rats to determine the degree of toxicity of the inorganic particles. This analysis found that samples of Mexicali dust are a mixture of 75% potassium aluminum silicates (illite) and 20% silica. The rats exposed to this dust developed a multifocal interstitial lung disease associated with deposits of the aluminum silicates. Mexicali dust induced biological activities and lung changes similar to those of asbestos and silica, suggesting that this material could be an etiologic agent of pulmonary fibrosis in exposed individuals.

In 1997, the U.S. Environmental Protection Agency, Region IX conducted a study to determine more precisely the sources and types of micro fractionated materials suspended in the air in the Imperial-Mexicali valleys[19]. The samples determined that annual averages for PM10 were exceeded on both sides of the border. On average, the greatest component of PM10 was geological material (50-60 percent). Soot was second, comprising approximately 25 percent of total PM10. Sulfates, nitrates, ammonium, aluminum, silica, titanium, calcium, and iron were other components, comprising between one and four percent of total PM10.

The California Center for Border and Regional Economic Studies (CCBRES) located at San Diego State University-Imperial Valley Campus reported that the PM10 levels in Imperial Valley were 80,414 tons per year and 71,323 tons per year for the city of Mexicali, according to the California Air Resources Board[20]. It should be noted that the data for Mexicali is somewhat misleading as it only accounts for the urban areas and does not include data for the whole valley.

The problem of air contamination in both valleys has created an alarming reaction with increasing cases of asthma and cardio respiratory illnesses. These health conditions are so alarming that the former president of Mexico, Ernesto Zedillo, initiated the *Program to Improve the Quality of the Air of Mexicali 2000-2005*[21]. The primary goal of this program intends is to

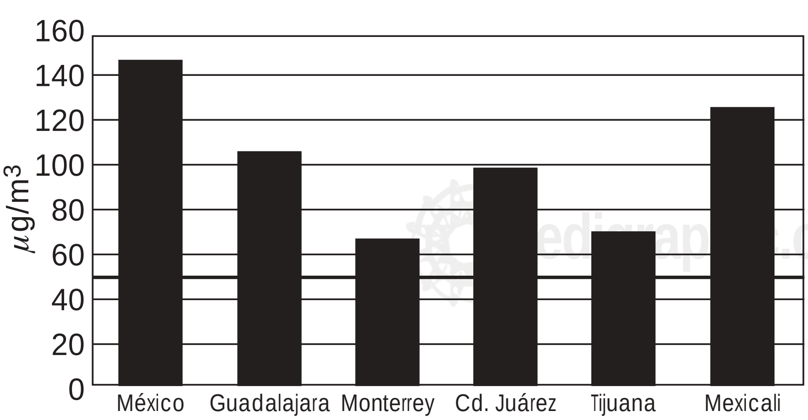

Figure 1. Average annual PM10 levels in major Mexican cities, 1997.

decrease the amount of PM10 in the region by 30 percent through the implementation of several programs. These include: inspection and vigilant enforcement of industrial and service establishments; vehicle inspections and sanctions on high polluters; urban transportation management; reforestation; increase the number of paved streets; landuse planning; and promotion of an environmental education program. The environmental education program is linked with binational border agreements and designed to encourage civic participation in environmental matters. To date, implementation of the program has been slow as financial support was not included.

Finally, an important study that quantifies the number of asthma cases in the Imperial Valley was conducted by English et al. in 1998[22]. This study did a comparative analysis of asthma rates in Imperial and San Diego counties. A few of the findings were that Imperial County had the highest rate for asthma hospitalizations for children under 14 years in the entire state of California. Additionally, from 1983 to 1994, there was a 59 percent increase in the hospitalization rates in Imperial County, compared to a reduction of nine percent in hospitalizations in San Diego County.

Each of the above studies sets the base of reference for the correlation between PM10 and respiratory illnesses in the Imperial-Mexicali valley. It is recommended though those additional binational studies are conducted to further understand the relationships between respiratory illnesses and air pollution.

MATERIALS AND METHODS

In order to organize the data used in this study, a clinical and environmental database for Mexi-

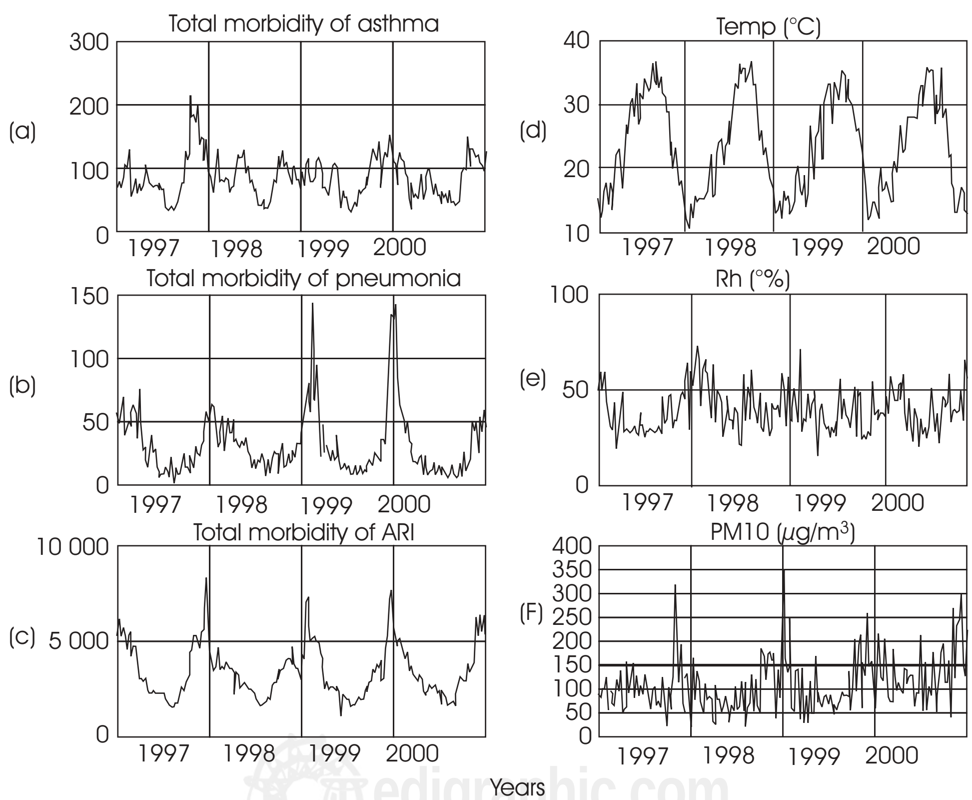

Figure 2. Hospitalizations from 1997 to 2000 in Mexicali for: (a) Asthma, (b) Pneumonia, (c) Acute Respiratory Infections (ARI); Atmospheric variables: (d) temperature, (e) relative humidity (f) PM-10 (thick dotted line indicates the 50 $\mu g/m^3$ annual air quality standard, and the solid thick line indicates the 150 $\mu g/m^3$ standard for a 24 hour period).

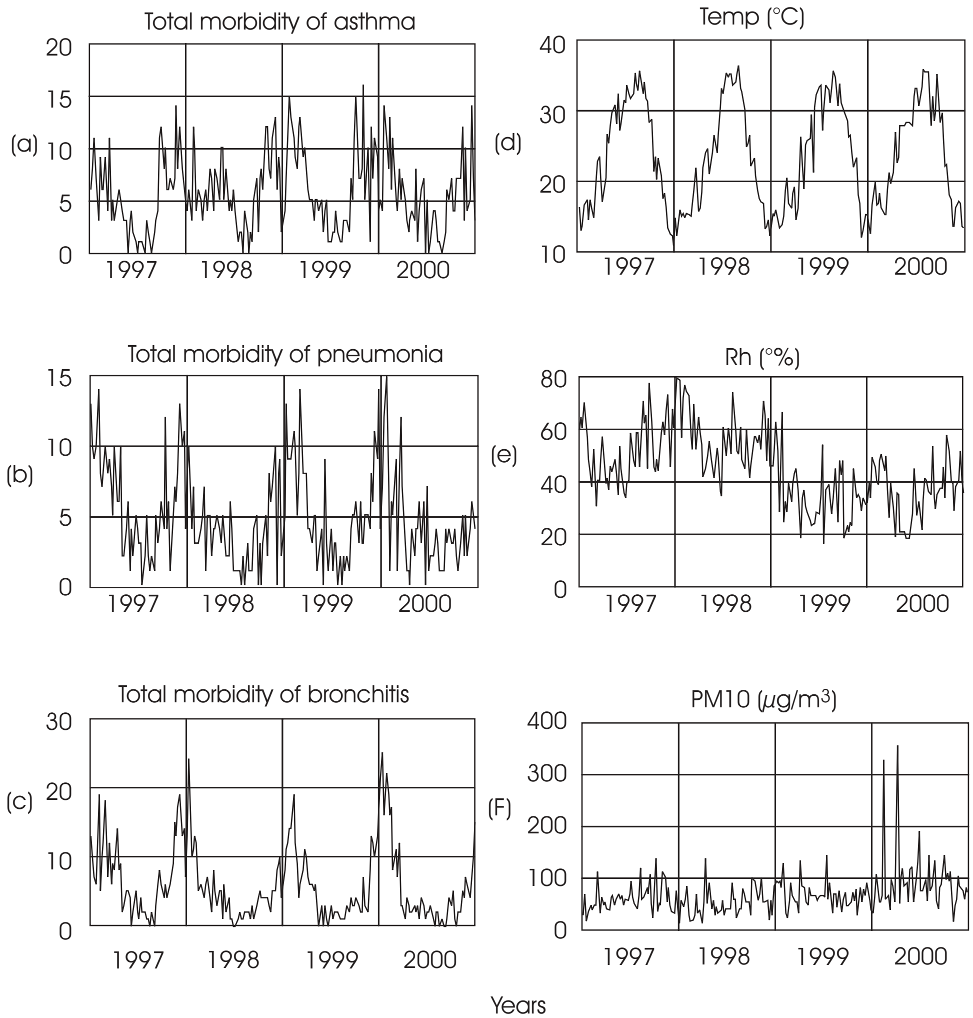

Figure 3. Hospitalizations from 1997 to 2000 in Imperial Valley for: (a) asthma, (b) pneumonia, (c) bronchitis; Atmospheric variables for: (d) temperature, (e) relative humidity (f) PM-10 (thick dotted line shows the 50 μg/m^3 annual air quality standard, and the solid thick line shows the 150 μg/m^3 standard for a 24 hour period).

cali and the Imperial Valley was generated. The time series included weekly data for the years 1997 to 2000. The original air pollution series was in 24 hour intervals but only weekly hospitalization data were available. For Mexicali, the clinical database contained time series data of asthma, pneumonia and acute respiratory illnesses (ARI). These data were collected from the clinical files supplied by Official Public Health Centers in Mexicali. For the Imperial Valley, the clinical database included time series data of asthma, bronchitis, and pneumonia. This data was supplied by the State of California Health and Human Services Agency, Office of Statewide Health Planning and Development[23].

The environmental database included the same time series for temperature, relative humidity, and PM10. All of the environmental data was supplied by the California Air Resources Board (CARB)[24], which manages six air monitoring stations in the city of Mexicali and eight stations in Imperial Valley. Both the environmental time series and clinical data vary between Mexicali and the Imperial Valley as seen in Figures 2 and 3.

The collection of the health data in the region was the most complex and difficult task in this project. In Mexicali, the data was available but not digitally. Therefore, all of the data had to be inputted into the database. Furthermore, the respirato-

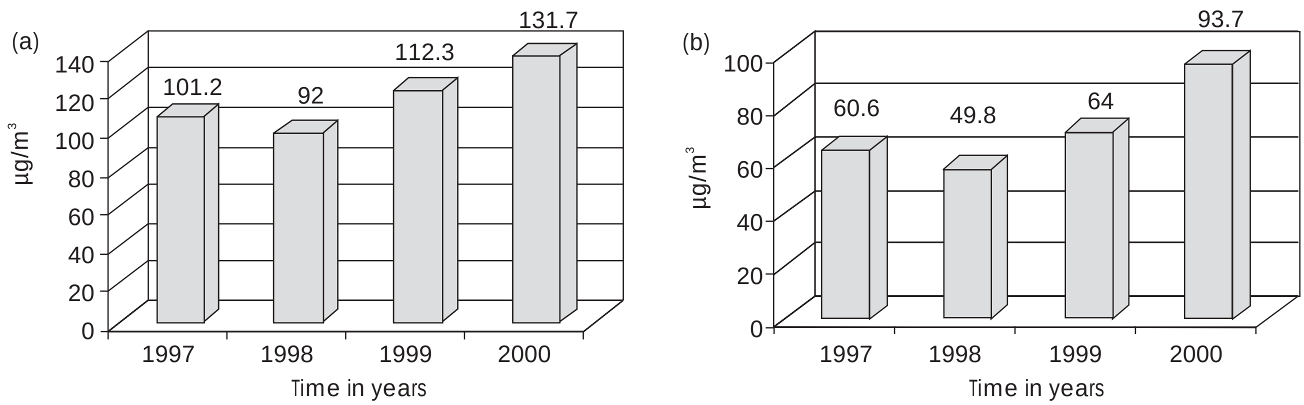

Figure 4. Annual PM10 Averages for Mexicali (a) and Imperial County (b).

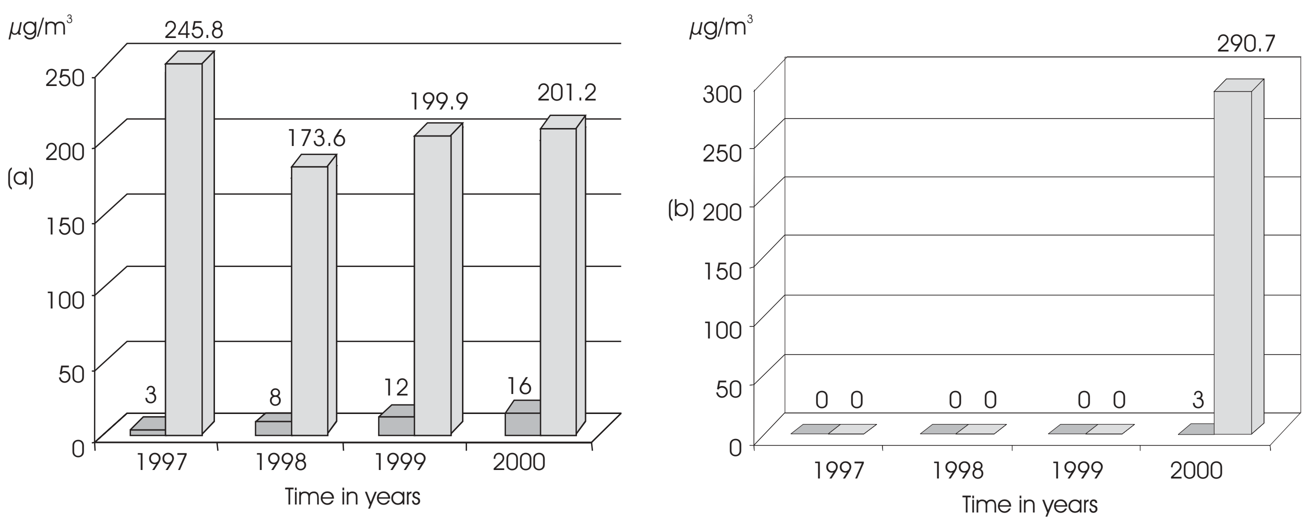

Figure 5. Number of Weeks that Exceeded the 150 μg/m³ Air Quality Standards in Mexico and the United States and the PM10 averages for those weeks in the year. (a) Mexicali (b) Imperial.

ry diagnoses by doctors in Mexico are grouped into one category called acute respiratory illnesses. This includes acute bronchitis, acute bronchiolitis, acute rinofaringitis, acute faringitis due to other specific organisms, acute infections of the superior respiratory pathways, and acute amigdalitis due to other specific organisms. This diagnosis process made it difficult to differentiate between respiratory illnesses in Mexicali.

In the Imperial Valley, the data was limited by only including hospitalizations in the region. Clearly, these data do not collect all of the cases in the area. Though it is not fully understood, it is estimated that many individuals in the region either self-medicate or visit doctors in Mexicali for monetary or cultural reasons. It could therefore be assumed that the number of asthma cases in the region is much higher than reported in the data collected. These factors (along with other possible factors) show that this analysis is limited in developing an absolute understanding of the impacts of PM10 on respiratory illnesses.

RESULTS

ANALYSIS BY YEARS

The PM10 annual standard of 50 μg/m³ was exceeded every year in Mexicali but only in 2000 in the Imperial Valley (see Figure 2f and 3f). The annual average of 50 μg/m³ was exceeded each year under study in both valleys, with the

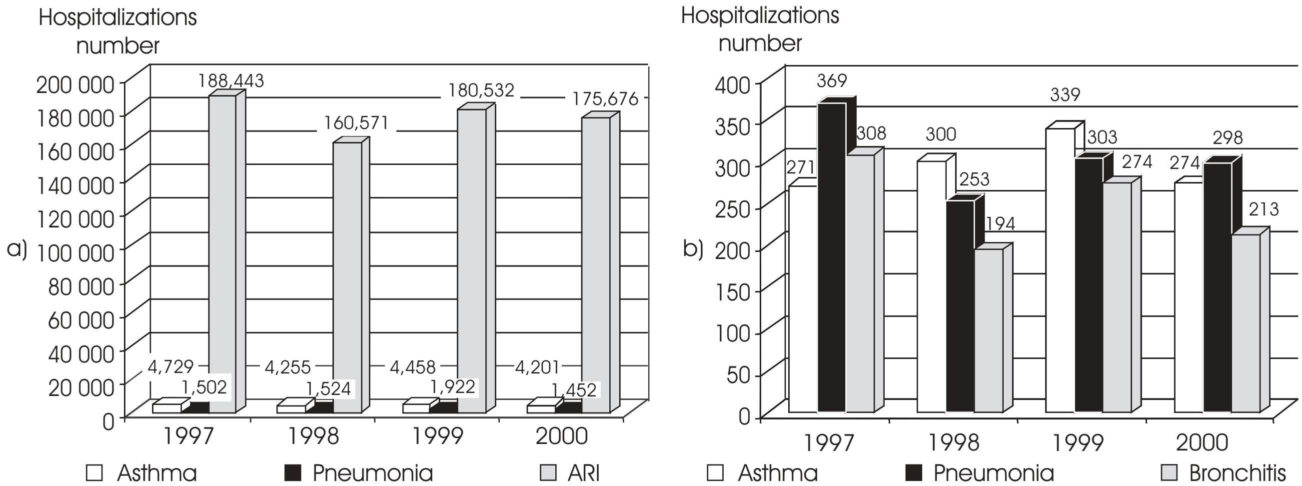

Figure 6. (a) Number of hospitalizations due to asthma, pneumonia and ARI in Mexicali, 1997 to 2000. (b) Number of hospitalizations from asthma, pneumonia, and bronchitis in Imperial County, 1997 to 2000.

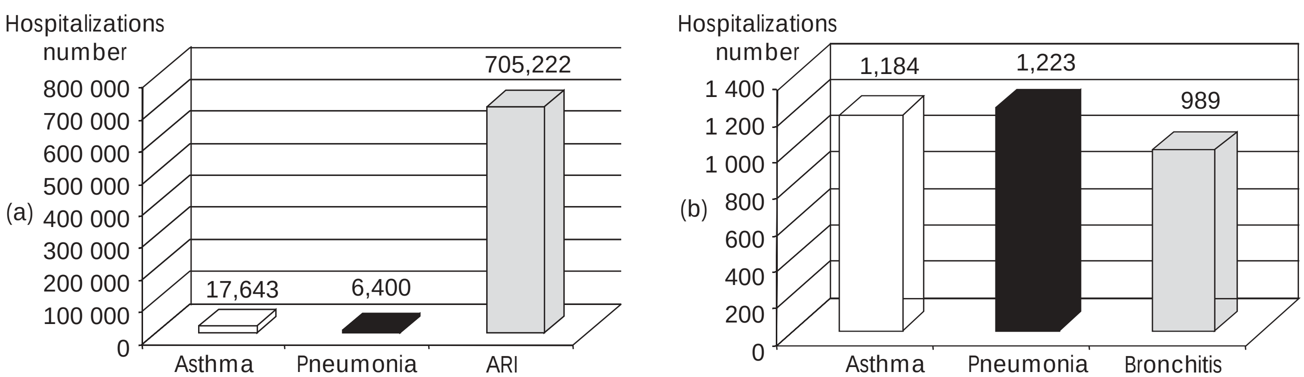

Figure 7. Total of hospitalizations occurs during 1997 to 2000 in (a) Mexicali and (b) Imperial.

exception of 1998 in which the level in Imperial Valley reached the maximum permissible level (see Figure 4).

Figure 5 displays the number of weeks that the PM10 standard was exceeded for the 24 hour norm of 150 $\mu g/m^3$ and provides the average PM10 levels for each week of the exceedances. In Mexicali (see Figure 5(a)), the PM10 standard was exceeded more than 3 weeks in 1997, and continued to rise each year thereafter. In Imperial County, the PM10 24 hour standard was exceeded for only three weeks in the year 2000 (see Figure 5(b)).

Figure 6 provides the number of hospitalizations for each selected pathology under study by year in Mexicali and Imperial Valley. Figure 7 gives the total hospitalizations for each pathology in both Imperial Valley and Mexicali for the years studied. This data makes it possible to determine the years with the highest and lowest hospitalization rates, to establish a visual association between the atmospheric and meteorological variables, and to create a correlation between the Imperial and Mexicali valleys. For example, it was possible to determine that on average Mexicali had more cases of asthma than bronchitis. Furthermore, if indices were calculated as a function of the population, Mexicali has a higher index of asthma than Imperial. Imperial and Mexicali have the same indices in the case of pneumonia. For the case of bronchitis it is not possible to compare indices of Imperial with indices of Mexicali because bronchitis is an illness that is included in the ARI group in Mexicali.

Table 2. Averaged Temperature, Relative Humidity, and Particulate Matter Smaller than 10 microns by season of the year, 1997 to 2000.

Mexicali Atmospheric Variables												
Season	Average Temperature				Average Relative Humidity				Average PM10			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	9.57*	13.77	14.78	14.99	27.25*	55.65	41.66	44.35	57.39*	92.82	148.21	139.88
Spring	24.81	20.87	20.73	23.50	30.03	39.28	36.41	33.41	98.51	67.44	79.59	121.43
Summer	32.21	32.98	31.22	32.11	30.30	38.87	36.85	38.28	90.50	71.39	74.82	103.77
Fall	24.23	23.52	25.92	22.77	41.51	37.93	35.91	42.11	121.46	131.1	136.95	149.05

Imperial County Atmospheric Variables												
Season	Average Temperature				Average Relative Humidity				Average PM10			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	12.11*	17.82	18.64	19.64	43.69*	88.9	65.05	49.8	33.64*	56.38	85.25	110.2
Spring	30.4	25.55	26.05	29.17	56.09	68.85	43.07	38.96	75.87	67.79	73.21	132.03
Summer	41.49	41.38	40.04	41.38	58.96	66.99	39.51	40.97	86.95	60.37	89.38	134.61
Fall	32.73	32.37	35.53	31.22	73.81	67.46	42.31	51.59	95.4	73.09	76.85	105.72

*Winter 1997 data is only for 2 months as the monitoring stations began operation in January 1997.

Table 3. Number of Hospitalizations for Asthma, Pneumonia, Acute Respiratory Illnesses/Bronchitis by Season, 1997 to 2000.

Mexicali												
Season	Asthma				Pneumonia				Acute Respiratory Illness			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	712*	1,262	1,165	1,376	417*	590	793	1,019	43,113*	59,391	62,863	67,820
Spring	1,005	1,223	1,120	901	481	482	406	225	40,355	40,721	40,242	37,207
Summer	646	700	629	702	126	232	154	131	24,913	25,855	23,630	27,076
Fall	1,815	1,233	1,361	1,290	243	280	278	293	50,590	45,818	41,760	46,643

Imperial Valley												
Season	Asthma				Pneumonia				Bronchitis			
	1997	1998	1999	2000	1997	1998	1999	2000	1997	1998	1999	2000
Winter	56*	76	130	101	82*	164	135	210	79*	88	100	106
Spring	61	83	51	51	106	61	74	56	85	54	74	56
Summer	19	32	46	35	26	19	18	22	34	24	29	39
Fall	83	109	112	87	85	43	46	34	64	45	52	40

*For the 1997 winter season, data from December 1996 is not available as data series began in January 1997.

SEASONAL ANALYSIS

Table 2 displays the average atmospheric variables by season for the respective years analyzed. Table 3 provides the hospitalization rates for asthma and pneumonia in both areas along with bronchitis in the Imperial Valley and acute respiratory illness in Mexicali by season of years under analysis.

These tables make it possible to determine which season of the year had the highest hospitalization rate and also what effect different atmospheric variables had on those hospitalizations. Fewer hospitalizations occurred during the summer season, in which the highest temperature and the lowest PM10 value were recorded. It is important to note that the average atmospheric-meteorological variables and clinical

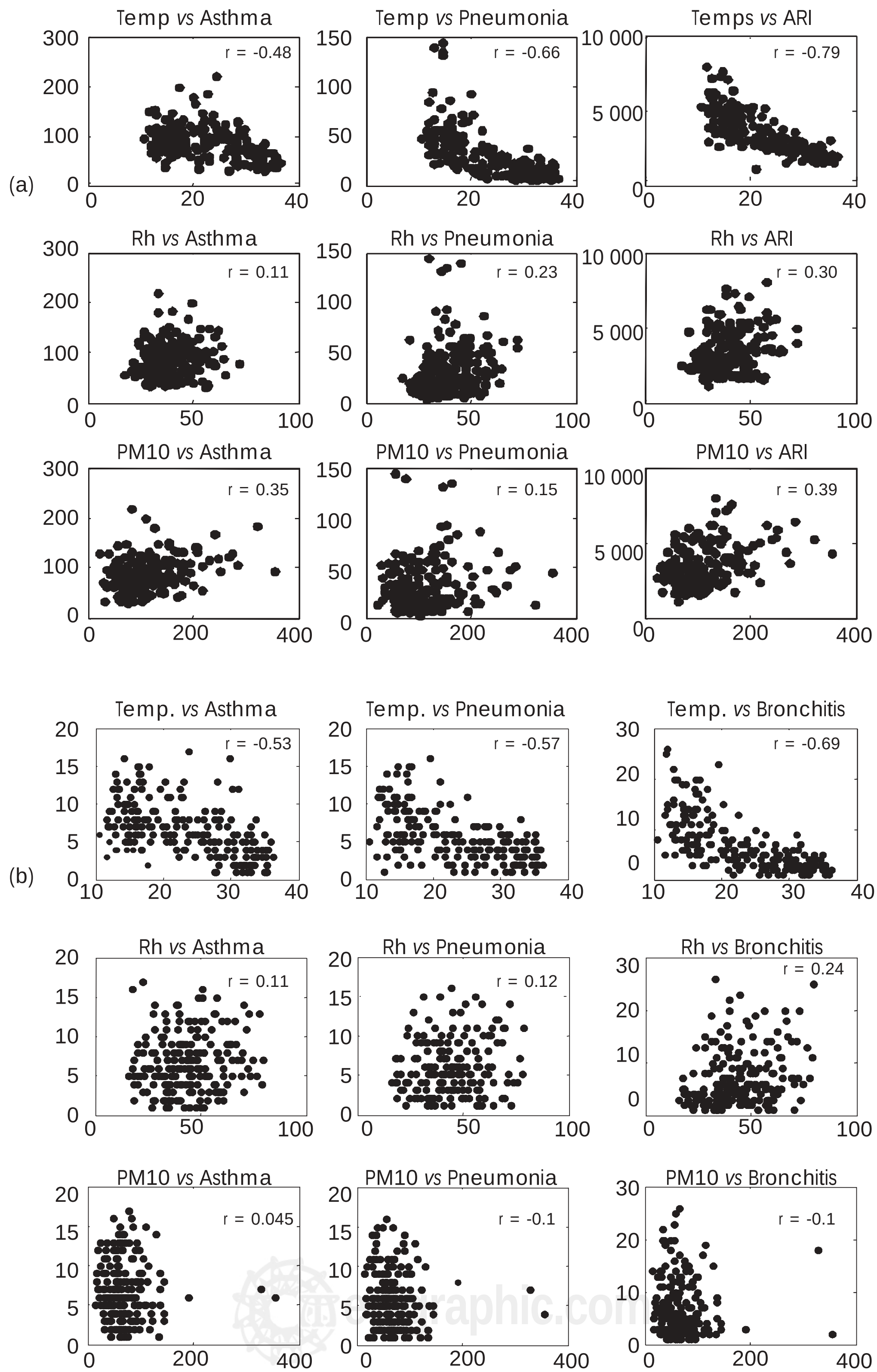

Figure 8. Dispersion graphs depicting the association between atmospheric variables with clinical variables in Mexicali (a) and Imperial (b).

Table 4. R^2 for Mexicali for asthma, pneumonia, and acute respiratory diseases each correlated with temperature, relative humidity and PM10.

Asthma Model	R^2
Temp, RH, PM10	0.80
Temp, PM10	0.75
Temp, RH	0.65
RH, PM10	0.43
Pneumonia Model	R^2
Temp, RH, PM10	0.67
Temp, PM10	0.67
Temp, RH	0.67
RH, PM10	0.21
ARI Model	R^2
Temp, RH, PM10	0.83
Temp, PM10	0.83
Temp, RH	0.79
RH, PM10	0.37

Table 5. R^2 for Imperial Valley for asthma, pneumonia, and bronchitis each correlated with temperature, relative humidity, and PM10.

Asthma Model	R^2
Temp, RH, PM10	0.70
Temp, PM10	0.61
Temp, RH	0.55
RH, PM10	0.31
Pneumonia Model	R^2
Temp, RH, PM10	0.68
Temp, PM10	0.61
Temp, RH	0.58
RH, PM10	0.20
Bronchitis Model	R^2
Temp, RH, PM10	0.80
Temp, PM10	0.78
Temp, RH	0.66
RH, PM10	0.22

Table 6. Estimated percentage of hospitalizations per year in Mexicali calculated from the models for: (a) Asthma, (b) Pneumonia, and (c) Acute Respiratory Infections (ARI).

		Year				
(a)	Asthma Model	1997	1998	1999	2000	1997-2000
	Model (T, RH, PM10)	4,089	4,084	4,282	4,326	16,781
	†Expected (PM10 = 0)	15.4% Less	14.4% Less	17.7% Less	19.9% Less	16.9% Less
(b)	Pneumonia Model	1997	1998	1999	2000	1997-2000
	Model (T, RH, PM10)	1,389	1,465	1,438	1,393	5,685
	†Expected (PM10 = 0)	2.3% Less	2.1% Less	2.7% Less	3.2% Less	2.6% Less
(c)	ARI Model	1997	1998	1999	2000	1997-2000
	Model (T, RH, PM10)	166,141	171,047	174,971	177,727	689,888
	†Expected (PM10 = 0)	14.5% Less	13.7% Less	16.9% Less	19% Less	16.12% Less

†Expected Hospitalizations for each model assume the value for PM10 is equal to zero $\mu g/m^3$ of air.

variables that correspond to winter 1997 consist of data for the months of January and February as the monitoring stations only began to operate adequately in January 1997. This explains why the average values for those dates are lower in comparison with later years.

Figure 8 is the dispersion graphs and r value of the simple regression analysis of the atmospheric and clinical variables. Note that when the dispersion graphs show a linear tendency behavior, the r values are larger. An example of this phenomenon is the correlation of temperature with each illness. Another interesting observation is that the weakest correlation is seen between relative humidity and asthma with a value of 0.11, followed by PM10 and pneumonia with a value of 0.15, and finally, relative humidity and pneumonia with 0.23.

Table 7. Expected number of hospitalizations in Imperial: (a) asthma model, (b) pneumonia model, and (c) bronchitis model.

		Year				
(a)	Asthma Model	1997	1998	1999	2000	1997-2000
	Model (T, RH, PM10)	338	355	347	345	1,385
	†Expected (PM10 = 0)	4.16% Less	4.0% Less	4.6% Less	5.43% Less	4.5% Less
(b)	Pneumonia Model	1997	1998	1999	2000	1997-2000
	Model (T, RH, PM10)	265	288	277	275	1,105
	†Expected (PM10 = 0)	6.7% Less	6.5% Less	8.0% Less	9.6% Less	7.7% Less
(c)	Bronchitis Model	1997	1998	1999	2000	1997-2000
	Model (T, RH, PM10)	301	318	311	310	1,240
	†Expected (PM10 = 0)	4.16% Less	4.0% Less	4.5% Less	5.4% Less	6.5% Less

† Expected hospitalizations for each model assume the value for PM10 is equal to zero $\mu g/m^3$ of air.

The weekly number of illnesses (i.e., asthma, ARI, pneumonia and bronchitis), can be considered as a Poisson random variable, due to this is a discrete variable that takes only positive integer values and its range should not be very large.

Poisson regressions that combined the temperature, relative humidity, and PM10 variables were utilized to obtain different models for asthma, pneumonia, and ARI in Mexicali. For the Imperial Valley, the same models were used but bronchitis was analyzed instead of ARI.

The R^2 value for the predictions obtained through multiple regression analysis for both valleys are seen in Tables 4 and 5. The highest R^2 value is found in the model that included all three variables—temperature, relative humidity, and PM10. The R^2 value in the correlation of asthma with temperature, relative humidity, and PM10 for Mexicali was 0.80. In the Imperial Valley for the same correlation, it was 0.70. In the asthma model, the R^2 value remained high with the removal of the relative humidity variable—indicating that relative humidity is not an important variable in the analysis of respiratory illnesses and PM10 levels. On the other hand, PM10 and temperature have stronger connections to the levels of asthma in the region as seen in R^2 values of 0.65 and 0.43 for Mexicali. In Imperial Valley, the R^2 was 0.55 in the correlation of temperature and relative humidity with asthma and 0.31 for the correlation of PM10, relative humidity, and asthma. The other R^2 values for pneumonia, ARI, and bronchitis are seen in Tables 4 and 5.

With these Poisson regression models, a number of experiments were conducted to determine the number of hospitalizations that would occur for asthma, ARI, and pneumonia in Mexicali if the levels of PM10 were zero during the same time period. Similar calculations were also done for the Imperial Valley. The results of these calculations are provided in Tables 6 and 7 for Mexicali and Imperial Valley, respectively. As seen in Table 6, in 1997 the number of asthma cases would have been 15.4 percent less in Mexicali if the PM10 levels had been zero. In the Imperial Valley, as seen in Table 7, the number of asthma hospitalizations in 1997 would have been 4.16 percent less if the PM10 values were zero. The differences in percentages between the Imperial Valley and Mexicali models show possible complications with the data.

DISCUSSION AND CONCLUSIONS

Through the exploratory analysis of the time series of the atmospheric variables (temperature, relative humidity, and PM10) and the clinical variables (asthma, pneumonia and bronchitis/acute respiratory infections (ARI)), it was possible to determine that the average annual air quality standard of 50 μg/m³ for PM10 was exceeded during the four years studied. It was also possible to locate the number of weeks per year that exceeded the 150 μg/m³ standard for PM10. Furthermore, it was possible to determine the number of hospitalizations for asthma, pneumonia, and bronchitis/acute respiratory infections that occur during the four seasons of the year (fall, winter, spring, and summer).

With the initial analysis, it can be concluded that temperature and PM10 levels have a greater impact on the clinical variables than relative humidity. However, such a conclusion cannot be supported quantitatively. For this reason, dispersion graphs and correlation coefficients were obtained. Under the Colton lineament, it was determined that the degree of correlation among variables was highest for the temperature variable. The coefficient between temperature and ARI was the strongest, with a value -0.79 (considered excellent); this was followed by pneumonia, with a good correlation of -0.66; and finally, asthma, with a moderate correlation of -0.48. Relative humidity showed a relatively low correlation of 0.39 for ARI, and null correlations between pneumonia and asthma of 0.23 and 0.11, respectively. The correlations of PM10 on asthma, pneumonia, and ARI/bronchitis were 0.35, 0.15, and 0.39, respectively, indicating a moderate effect on asthma and ARI/bronchitis and a null effect on pneumonia.

With this new information, it was possible to determine:

- That temperature has an important impact on the three pathologies studied
- That relative humidity does not have a linear affect on pneumonia, asthma, ARI in Mexicali and on bronchitis in Imperial
- That PM10 has an affect only on asthma and ARI.

Determining the type of distribution for each variable provides insight into the type of model or models that are helpful a regression analysis. In this case, as often happens with this type of data, the majority of temporary series that were analyzed followed a Poisson distribution, and therefore, these were used to derive the models for each illness.

In the case of asthma, the model lowered its confidence from 0.86 to 0.70 when relative humidity was not considered, from 0.86 percent to 0.65 when PM10 was omitted, and from 0.86 to 0.43 when temperature was disregarded. These omissions show that temperature and PM10 have a greater influence on asthma than relative humidity.

For the pneumonia model, the R^2 value stayed nearly the same, 0.67 to 0.67 for Mexicali, and 0.68 to 0.58 when relative humidity and then PM10 were eliminated. However, it went down dramatically from 0.67 to 0.22 for Mexicali and from 0.68 to 0.20 for Imperial when temperature was omitted. This demonstrates that pneumonia is more sensitive to temperature, and less sensitive to relative humidity and PM10.

The ARI/bronchitis model maintained the R^2 value of 0.83 when relative humidity was omitted, and decreased slightly from 0.83 to 0.79 when PM10 was omitted. When temperature was omitted in this model, the R^2 value decreased from 0.83 percent to 0.37 percent. This indicates that ARI/bronchitis is highly sensitive to temperature, less sensitive to PM10, and has no relationship to relative humidity.

Once these three models were derived, they were used to determine the number of hospitalizations from 1997 to 2000 that could have been avoided if the PM10 levels could have been zero. For the asthma model, it was found that there could have been 15.4 percent less hospitalizations in 1997, 14.4 percent less in 1998, 17.7 percent less in 1999, and 19.9 percent less in 2000. The pneumonia model concluded that there could have been 2.3 percent less hospitalizations in 1997, 2.1 percent less in 1998, 2.7 percent less in 1999, and 3.2 percent less in 2000. In the ARI/bronchitis model, there could have been 14.5 percent less hospitalizations in 1997, 13.7 percent less in 1998, 16.9 percent less in 1999, and 19 percent less in 2000.

When making an informed decision related to the environment or at least one with the lowest degree of error possible, the availability and reliability of information is critical. Intuition, for example, that air pollution in a city causes illness in people is not enough. It needs to be demonstrated but this is not a trivial task as there are many different aspects from anthropogenic to natural that enter the equation. Therefore, it is necessary to try and understand all of the aspects that are part of this equation and rank them appropriately. Clearly, environmental concerns are one of the most important elements in the equation and need to be included in the decision making process. This project provides additional information about the environment in the Imperial-Mexicali valleys that can help decision makers in the region take actions to improve the quality of air in the binational airshed.

This work considered only PM10 as a factor of pollution, and temperature and relative humidity as meteorological variables. It studied the how meteorological variables impact PM10. Also, it analyzed how PM10 influences asthma, pneumonia, and ARI/bronchitis. The experiments demonstrated that temperature has a greater impact on the respiratory diseases studied than relative humidity and PM10. This is shown in the fact that not all of the respiratory diseases responded in the same level when correlated with PM10 and the meteorological variables.

The Poisson regression models predicted that asthma, pneumonia, and ARI are much more sensitive to temperature than to PM10, and have a very low relationship to relative humidity. Pneumonia, for example, shows null sensitivity to PM10. On the other hand, asthma shows more sensitivity to PM10 than ARI. The fact that pneumonia and ARI/bronchitis are not as sensitive to PM10 does not mean that other atmospheric pollutants like carbon monoxide (CO) or ozone (O_3) are not harmful. In fact, the standards of these elements are also frequently exceeded in Mexicali. The confidence percentage in the predictions could have been improved if these elements were included when the models were designed.

These results were derived from the analysis of clinical and atmospheric-meteorological data done on a weekly basis. However, it is useful to conduct studies with more in-depth analysis or for a shorter period of time, such as for a 24 hour period or by geographical areas in the cities. These types of tests are being explored and call for further work within this line of research.

ACKNOWLEDGMENTS

This research work has been partially sponsored by the Universidad Autónoma de Baja California (UABC), *Southwest Center for Environmental Research and Policy* (SCERP) and by the *Fulbright Scholarship Board* (FSB) from the Border Academic Program, COMEXUS.

BIBLIOGRAPHY

1. United Kingdom Ministry of Public Health. 1954. Mortality and Morbidity during the London Fog of December 1952. Reports on Public Health and Medical Subjects, No. 95. London: Her Majesty's Stationary Office.
2. Borja VH. Estudios ecológicos. Salud Pública de México 2000; 42: 533-538.
3. Díaz J, García R, Ribera P, Alberdi JC, Hernández E, Pajares MS, Otero A. Modeling of air pollution and its relationship with mortality and morbidity in Madrid, Spain. International Archives of Occupational and Environmental Health 1999; 72: 366-376.
4. Ostro BD. Cómo estimar los efectos de la contaminación atmosférica en la salud. Estudios Públicos 1998; 69: 105-113.
5. Pajares OMS, Díaz JJ, Montero RJC, Alberdi OJC, Mirón PIJ. Mortalidad diaria en la Comunidad de Madrid durante el período 1986-1991 para el grupo de edad de 45 a 64 años: su relación con la temperatura del aire. Revista Española de Salud Pública 1997; 71(2): 149-160.
6. Pope CA III, Dockery DW, Spengler JD, Raizenne ME. Respiratory Health and PM_{10} Pollution. American Review of Respiratory Diseases 1991; 144: 668-674.
7. Pope CA III, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW Jr. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. American Journal of Respiratory and Critical Care Medicine 1995; 151: 669-674.
8. Schenker MB, Gold EB, Lopez RL, Beaumont JJ. Asthma Mortality in California, 1960-1989. American Review of Respiratory Diseases 1993; 147: 1454-1460.
9. Maréthoz E, Lacroix JS, Moeschler MB, Hogendijk S, Spertini F, Polla BS. Allergy and the Environment: A Meeting Report. Reviews on Environmental Health 1999; 14: 63-78.
10. California Department of Health Services, Environmental Health Investigations Branch. California County Asthma Hospitalizations Chart Book. California DHS (August 2000). 2000 www.ehib.org
11. IseSalud 1998. Informe Semanal de Casos Nuevos de Enfermedades.
12. Reyna MA, Alvarez JE. El último suspiro de vida. Ciencia y Desarrollo, Ed. CoNaCyT Julio/Agosto 2001; 159: 40-45.
13. Instituto Nacional de Ecología (INE-SEMARNAP). Segundo informe sobre la calidad del aire en ciudades mexicanas. CENICA. (accessed January 2002) www.ine.gob.mx/INE?documents/cal_aire/reporte/portada.html. 1998.
14. Cornejo JA. Empresas de EUA construyen dos termoeléctricas en Mexicali; de 100 mdd, la inversión total" La Jornada. (17 de julio) 2002.
15. Cornejo JA. Termoeléctricas en Mexicali no cumplirán con los requisitos ambientales de EUA. La Jornada. (23 de octubre) 2002.
16. Inventario de emisiones de Mexicali. Informe Final (Versión Final). Preparado para: Grupo Técnico del Inventario Mexicali. Preparado por: Ingeniería de Control Ambiental y Riesgo Industrial, S. de R. L. M. I. Septiembre 1999.
17. Collins K, Kathryn CD, Reyna CMA. *Environmental Health at the California-Baja California Border: Forum Report*. (April). Calexico: California Center for Border and Regional Economic Studies. 2002.

18. Osornio-Vargas AR, Hernández-Rodriguez NA, Yáñez-Buruel AG, Ussler W, Overby LH, Brody AR. Lung Cell Toxicity Experimentally Induced by a Mixed Dust from Mexicali, Baja California, Mexico. Environmental Research 1991; 56: 31-47.
19. Chow JC, Watson JG. Imperial Valley/Mexicali Cross Border PM10 Transport Study. Draft Final Report." EPA-CICA (accessed February 2002) www.epa.gov/tth/catc/cica/cicaeng.html#Imperial. 1995
20. CCBRES. Understanding Air Quality and Health in the Binational Air Basin of the Imperial and Mexicali Valleys. (Summer) Calexico, CA: California Center for Border and Regional Economic Studies (CCBRES). 2001.
21. Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP), Gobierno del Estado de Baja California, Gobierno Municipal de Mexicali, Secretaría de Salud. Programa para Mejorar la Calidad del Aire en Mexicali. Available at: http://www.semarnap.gob.mx/quincenal/qui-56/personal.htm [accessed January 30, 2002]. 1999.
22. English PB, Von Behren J, Harnly M, Neutra R. Childhood asthma along the United States/Mexico border: hospitalizations and air quality in two California counties." Pan American Journal of Public Health 1998; 3: 392-399.
23. Office of Statewide Health Planning and Development, Healthcare Quality and Analysis Division. Public Patient Discharge Data. Data received October 2002.
24. California Air Resources Board (CARB). 1997-2000 air quality data bases for Mexicali and Imperial Valley provided by Gabriel Ruiz, California Environmental Protection Agency, Air Resources Board, Sacramento, CA. 2000.