

**Seasonal and Spatial Variation of Metals in Airborne
Particulate Matter in El Paso (USA)--Juarez (Mexico)
Airshed**

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Abstract

Airborne particulate matter is a serious problem in the El Paso--Juarez binational region (United States of America -- Mexico). El Paso, Texas has been considered as a non-attainment area. El Paso was listed as serious in the National Air Quality and Emissions Trends report (1996), occupying the 15th place. Non-attainment status is for particulate matter, ozone and nitrous oxides. Thus, it is important to characterize particulate matter constituents from the health point of view for border residents. Concentrations of Cu, Pb, Cr, and As, which are toxic were determined by inductively coupled plasma mass spectrometry. Levels were found to increase during fall and winter, relative to spring and summer, over a 3-year period of 1994 through 1996. Ground-level atmospheric inversions during the colder seasons in this desert region are believed to trap anthropogenic particulates by preventing vertical mixing. The distribution of elevated metal levels suggests local sources of the anthropogenic particulate matter. Pollutants are released on both sides of the border. International cooperation is essential to monitor and regulate particulate matter in this binational airshed.

Keywords: Air pollution; Metals; ICP-MS; US--Mexico border; Particulate matter

1. Introduction

El Paso and Ciudad Juárez are contiguous cities that sit on both sides of the U.S.--Mexico border, separated by the Rio Grande, which cuts through the Franklin Mountain and the Sierra de Juárez. Air quality may be the most fundamental environmental challenge in large urban areas along the border. Air crosses that border freely in both directions affecting every resident. El Paso, Texas has been considered as a non-attainment area. El Paso was listed as serious in the National Air Quality and Emissions Trends report (1996), occupying the 15th place. Non-attainment status is for particulate matter, ozone and nitrous oxides (National Air Quality and Emissions Trend Report, 1996). Chow and Watson concentrate on the sources influence of particulate matter as well as other combustion sources and their cross-border impact for the Imperial Valley/Mexicali (Chow and Watson, 2001). The Imperial Valley/Mexicali is another non-attainment border area for particulate matter. Source contributors were investigated for a period of a year and seven months in a 20 by 80 km area through monitoring sampling sites. Long-term data sets are scarce in general and understanding of the composition of particulate matter is inadequate.

In the El Paso--Juárez airshed, lack of rain and vegetation, a windy climate, extensive unpaved urban areas, an aged vehicle fleet, and industrial emissions coalesce to make particulate matter in our air a serious environmental problem. The present study will help to understand the composition, toxicity, and origin of particulates.

El Paso, Texas (USA) and Ciudad Juárez, Chihuahua (Mexico) are contiguous cities straddling the Rio Grande, which forms this section of the international border (Fig. 1). The population of El Paso is approximately 800,000, and that of Cd. Juárez is estimated to be in excess of 1.5 million. Ciudad Juárez residents have limited municipal services, at times with unplanned and unpaved neighborhoods at the edge of the city in areas known as *colonias*.

Population growth has been rapid in recent years, particularly since 1980. Manufacturing and fabrication have developed dramatically in Cd. Juárez with maquiladoras (US General Accounting Office, 1992; Maquila Scoreboard, 2000). US firms

sought cheaper labor costs south of the border affecting the area growth, and more recently in response to the favorable import-export climate generated by the North American Free Trade Agreement/NAFTA (U. S. International Trade Commission, 1997; US Environmental Protection Agency, 1996).

Much of the region lies at an elevation of approximately 1100-1200 m, with local mountain ranges (Franklin Mountains, Hueco Mountains, and Sierra de Juarez) reaching up to nearly 2000 m. This arid region is at the northern end of the Chihuahuan desert belt, an elevated continental rain-shadow desert characterized by extremely hot summers and cool winters, with most rainfall (here 20 cm/yr) occurring in brief thunderstorms during July, August, and September.

The urban area is surrounded in general by undeveloped desert land, with the exception of the Rio Grande valley. The valley is up to approximately 10 km in width, and supports a rich agriculture, including chile peppers, cotton, and pecans. Irrigation is provided directly from the river and from shallow wells recharged from the river's underflow. The original settlement of the region was centered on the Rio Grande, with subsequent expansion (after arrival of railroads in the 1880s) out of the river valley into the surrounding desert. Urban growth northward in El Paso (east of the Franklin Mountains) has been limited by three military installations Fort Bliss, Biggs Army Air Field, and White Sands Missile Range.

Einfeld and Church (1995) reported on a short-term (December 3-21, 1990) investigation of particulate matter in the El Paso--Juarez airshed. Their study pointed out the importance of biomass combustion and crustal sources of particulate matter, and the relatively small contribution (< 20%) from vehicles. Levels of particulate matter were higher in Cd. Juarez than in El Paso, and much of this was aerosol carbon. Winter stagnation events were found to exacerbate the particulate load by preventing dilution. Einfeld and Church (1995) also provided a comprehensive summary (to 1995) of the findings of earlier research on all aspects of air quality in the region.

Dattner (1994) furnished additional details of x-ray fluorescence analysis of 72 (22 coarse, 50 fine) 12-hour filters also collected during the December 1990 study. He indicated that elevated metal values were consistent with a smelter source, and that

high lead values in Cd. Juarez were related to leaded gasoline. By the mid-1990s, leaded gasoline was severely restricted in Mexico.

Our purpose was to examine air quality over a longer span of time than in previous investigations. In the present three-year study we attempt to initiate the examination of trends, and how they change with season. Future studies would benefit from this information. Also, we will scrutinize the changes in air quality over time as conditions in the El Paso--Juarez metroplex altered. On a spatial basis, we hoped to spot area sources of metals consistent over time. We focus on metal pollution, the bulk of which is believed to be anthropogenic.

2. Materials and methods

Meteorological records were investigated from two sources, in a local newspaper *The El Paso Times*, and from the US National Weather Service. The goal was to find one low-wind-velocity day in each of the four seasons, winter, spring, fall, and summer, of the years 1994, 1995, and 1996. Interest on low wind speeds was raised from concern with production of sampling conditions reflecting predominantly local production of particulates.

Pearson and Fitzgerald applied the MM5 wind model for the El Paso-Juarez; their model was concern with high ozone concentration days. For ozone high episodes they studied stagnant and weak early morning surface winds. Pearson and Fitzgerald findings expose low wind speeds for the Paso Del Norte Area while high ozone episodes occur.

Limited meteorological data is available, and old archived filters do not have sufficient data for a more detailed meteorological study. Wind speeds were studied for selection of filters sampled on an every sixth day basis. The selection criterion was low wind days, representative wind direction (Fig. 2. El Paso Wind Rose), and the lack of adverse (rain, snow, etc.) conditions to find a characteristic day of the four seasons: spring, summer fall and winter. Filters were then retrieved from the stored collection (dates and wind speeds shown in Table 1). Among the available filters we were able to select days with average wind speeds between 5.8 and 14 km/hr (3.6 to 8.8 MPH, Table

1).

After selecting the filter based on the weather data available, filters were sub-sampled at the laboratory in El Paso City-County Health and Environmental District (EPCCHED). Segments of the filters measuring 3 by 1 inches were sub-sampled for analyses using a ceramic knife (zirconia) to prevent contamination with metals of interest.

A total of 141 PM₁₀ quartz filters from the archived collection of the EPCCHED were sub-sampled for analytical purposes. These 24-hour samples had been taken from 4 sites in El Paso, Texas (USA) and 5 in Ciudad Juarez, Chihuahua (Mexico). Samples had been taken on a six-day rotation, with a 24-hour, midnight-to-midnight sample collected every 6 days. The sampler systems, two-stage Sierra Andersen PM₁₀, were impaction type with size-selective inlet and a design flow rate of 1.13 m³/min (US Environmental Protection Agency, 1992).

Table 1. Weather data used for selection of appropriate PM-10 filters.

	Wind average speed MPH	Peak wind MPH
DATES FOR 1996		
10/30/96	3.6	10
07/26/96	4.8	15
04/15/96	8.2	22
01/10/96	7.8	24
DATES FOR 1995		
10/18/95	5.3	16
07/08/95	5.3	16
04/27/95	7.3	23
01/03/95	5.4	16
DATES FOR 1994		
10/11/94	4.6	14
07/31/94	7.2	23
04/20/94	8.8	22
01/08/94	4.8	9

The four El Paso sites were Tillman, Riverside, Northeast, and Ivanhoe, and the five Cd. Juarez sites were 20-30, Pesta, Tecno, Advance, and Zenco. Figure 1 presents these locations and a regional map. Duplicate samplers are sited at Tillman (Tillman A and B)

and Tecno (Tecno 1 and 2), collocated samplers in this locations render high precision replicate results. The sites had been selected previously using siting criteria under the 1987 PM₁₀ regulation (US Environmental Protection Agency, 1987).

The 4 peripheral sites (Northeast, Ivanhoe, Zenco, and Tillman) enclose or bound a roughly rhomboidal area of approximately 250 km². Fig. 1 indicates that the two western sides of the rhomboid abut, respectively, the Franklin Mountains in Texas, USA, and the Sierra de Juarez in Chihuahua, Mexico.

For microwave extraction we followed the protocols of US Environmental Protection Agency Method 3051 *Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils* (US Environmental Protection Agency, 1994). Extractions were performed in a CEM MDS-2000 microwave unit with sealed Teflon reaction vessels.

For quality control, in each carousel of 12 reaction vessels we included a laboratory fortified blank and a laboratory fortified sample (matrix blank) with US National Institute of Standards and Technology (NIST)-traceable spikes.

Inductively coupled plasma mass spectrometry (ICP-MS) analysis was performed on the filter extracts. Plasma high temperature raises electrons to their ground state, the mass spectrometer quantifies elemental concentrations having high sensitivity and low detection limits. Thus, the ICP method of analysis offers the advantage of being highly sensitive and offers 65 quantifiable elements as response, it destroys the filter sample (Chow, 1995). For ICP-MS analyses we used a Hewlett Packard HP 4500 instrument. We followed appropriate protocols in two US Environmental Protection Agency methods: *Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma-Mass Spectrometry* and *Determination of Metals in Ambient Particulate Matter Using Inductively Coupled Plasma /Mass Spectrometry (ICP/MS)*. The first of these is Method 200.8 and the second a preliminary draft Method, EPA/625/R-96/010a (US Environmental Protection Agency, 1991; 1997). We corrected for interferences from polyatomic ions from gas, air, reagents, and sample matrices using appropriate protocols (US Environmental Protection Agency, 1991; 1997). Samples were analyzed for 65 elements, of which some 30 elements typically were found consistently at quantifiable levels. All results presented herein fell within the relevant US Environmental Protection

Agency guidelines. Additional analytic details are found in Espino (2000).

3. Results and Discussion

We focused our attention on four elements of particular interest in the El Paso--Juarez airshed: copper, lead, arsenic, and chromium. There are no significant natural sources of these elements beyond typical crustal (mineral) background in the region; thus they represent chiefly anthropogenic input. Lead and Arsenic were sampled and discussed in the US Department of Health and Human Services "*Review of Historical Soil Sampling Results*" for the El Paso County (Health Consultation, 2001). The referred soil samples were taken in consideration in four theses from the University of Texas at El Paso and monitor the metals concentration in the vicinity of schools and recreational parks at the central El Paso area. The other data set consisted of the old Texas Air Control Board collected surface soil.

Our selection of the four elements from thirty available is based on a concern owing to their toxicity and on an attempt for concise analyses. Concentrations of these elements for each sampling site have been plotted on geographic information system (GIS) displays of the El Paso--Juarez metroplex (Fig. 3, 4, 5 and 6).

The 4 triple-map figures present concentrations of the four elements during each of the four seasons of 1994, 1995 and 1996. The same data for all three years also are presented as tables 2, 3, 4, and 5 to emphasize the cyclical nature of pollutant levels.

In Figures 3, 4, 5 and 6 the concentrations of the elements tend to correlate across stations on each sampled day, i.e., there are days with high values across the map and other days with low values. This reflects a degree of interconnectedness of the airshed in terms of meteorological conditions and production of pollutants.

Interconnectedness notwithstanding, outlying stations, those most distant from the industrial districts and other known pollutant sources in both El Paso and Cd. Juarez, consistently show the lowest concentrations. This obviously reflects both the greater production of pollutants in the core urban areas and the degree of mixing in the airshed on these generally calm-wind days. In particular, the Northeast station in El Paso records

good quality air (for these 4 elements in particulate matter), reflecting the low-density residential land-use, the distance from major pollutant sources, and the open land that surrounds this neighborhood on three sides.

In contrast, the central stations, Tillman in El Paso Advance Transformer, and Pesta in Cd. Juarez, typically show the highest values. The northern part of Cd. Juarez is the site of many maquiladoras, "twin plants" which perform manufacturing and fabrication operations for foreign (non-Mexican) companies under special tax and tariff arrangements. In addition, there are other local industries there, and scattered throughout Cd. Juarez. Environmental enforcement is often difficult in Mexico when compared to the US, but environmental regulations are similar. The large ASARCO copper-ore smelter is located less than 5 km to the NW of the Tillman station in downtown El Paso, TX. This operation was a significant, but not dominant, point source of metal- and semi-metal-bearing particulates. The ASARCO smelter was shut down in February 1999; no date for reopening has been set.

Figures 3, 4, 5 and 6 demonstrate the cyclical nature of seasonal variation in particulate pollution. Fall and winter levels of Cu, Pb, As, and Cr are considerably higher than spring and summer values -- often by more than an order of magnitude at individual stations. This effect is seen most consistently in fall and winter (1995 and 1996) for all four elements.

With one exception, there is no evidence for significant seasonal changes in pollutant releases in the region. The burning of non-standard materials for fuel in fireplaces and heating stoves for residential heating does occur in Juarez during the colder months of the year. The practice is unusual in El Paso. Burning such materials as tires and trash may release metals to the air and contribute to pollutant levels, mainly in or contiguous to Cd. Juarez.

Retarded vertical circulation in the El Paso--Juarez airshed is believed to be the major cause of the increased levels of anthropogenic pollutants, i.e., the Cu, Pb, As, and Cr, in fall and winter. Atmospheric inversions are common at that time of year, with rapid radiative cooling at ground level at night due to elevation and the typical lack of cloud cover. Occasionally these inversions last several days, with consequent trapping of

pollutants near ground level, and significant deterioration of air quality.

It has long been realized that the El Paso--Juarez airshed has a high loading of natural mineral material in its ambient particulate matter (Dattner, 1994; Einfeld and Church, 1995). The extremely dry climate and often-windy weather, sparsity of vegetation, and prevalence of unpaved streets and roads, particularly in Cd. Juarez, combine to release natural particulate matter into the local atmosphere. These processes are augmented by production and escape of mineral particulate matter from quarry operations within the limits of both cities.

The mineral components of the El Paso--Juarez airshed are not reflected, by choice, in the data discussed herein. Our emphasis is on the origin of the toxic metals and semi-metals in the local particulate matter.

There are no current metal-ore mining operations in the region and no extensive mining spoil piles to act as a source of the Cu, Pb, As, and Cr which we observed. The local geologic section consists chiefly of Paleozoic and Mesozoic sediments, many of which are carbonates, and unconsolidated Tertiary and Quaternary sediments (Hawley, 1978). The relatively minor exposures of igneous and metamorphic rocks also are not significant sources of those metals.

Obvious industrial sources of metals in the airshed include a copper-ore smelter and light industry in El Paso. Cd. Juarez houses a large number (several hundred) of *maquiladoras*, various industries, and small, essentially unregulated operations such as brick kilns (these often burn tires, pallets, sawdust, etc. as fuel).

4. Conclusions

Metals concentrations (Cu, Pb, Cr, and As) are highest in the fall and winter seasons, apparently due to retarded vertical circulation associated with inversions. Fall and winter levels may be an order of magnitude higher than spring and summer levels.

Geographically, metal concentrations typically decrease from the urban central part of El Paso--Juarez. Concentrations in the urban core often are an order of magnitude or more greater than those recorded at distal stations. Smelter operations in El Paso appear to have made a significant, but not dominant, contribution to metals in particulate matter

in the airshed. Industrialization and population growth combined with poverty are contributing to emissions in Cd. Juarez.

Continuing international cooperation is required to monitor, assess, and regulate anthropogenic sources of metals in the air shared by El Paso and Cd. Juarez.

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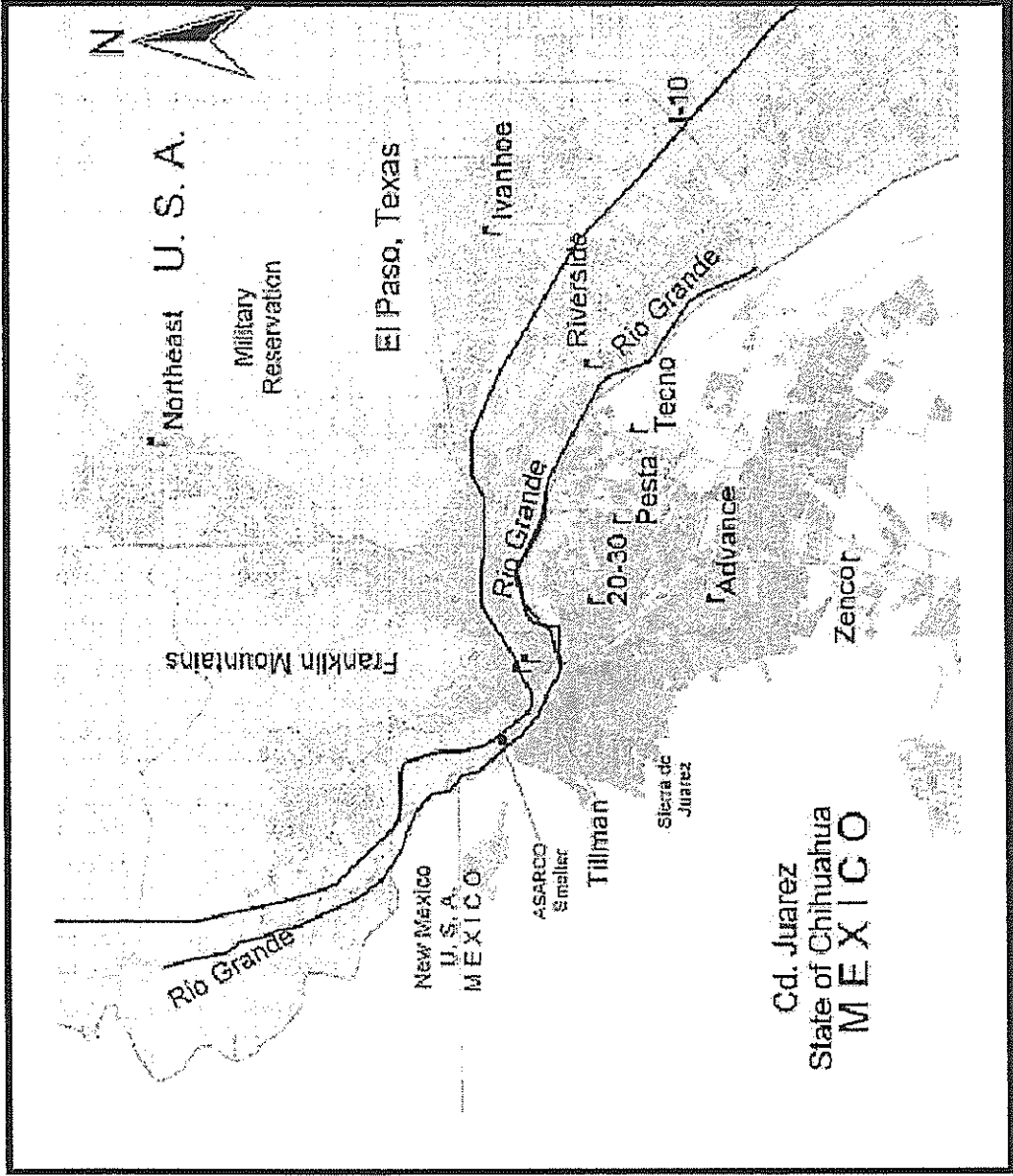


Fig. 1. Regional map of the El Paso--Juarez binational airshed, depicts location of sampling stations and significant geographic and cultural features.

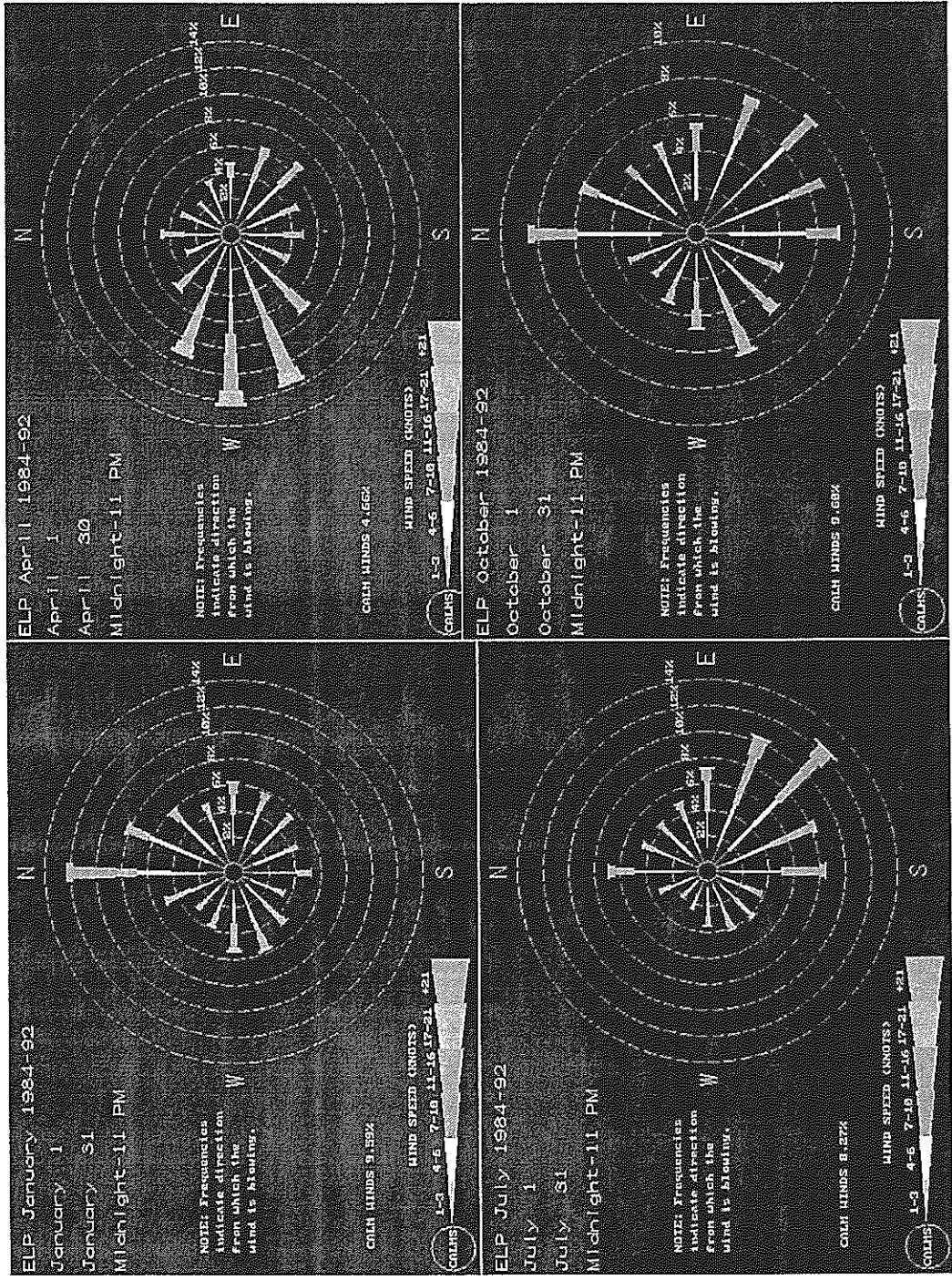


Fig 2. El Paso Wind Rose from 1984 to 1992. For the selected months representing the four seasons of the year (winter, spring, fall and summer counterclockwise).

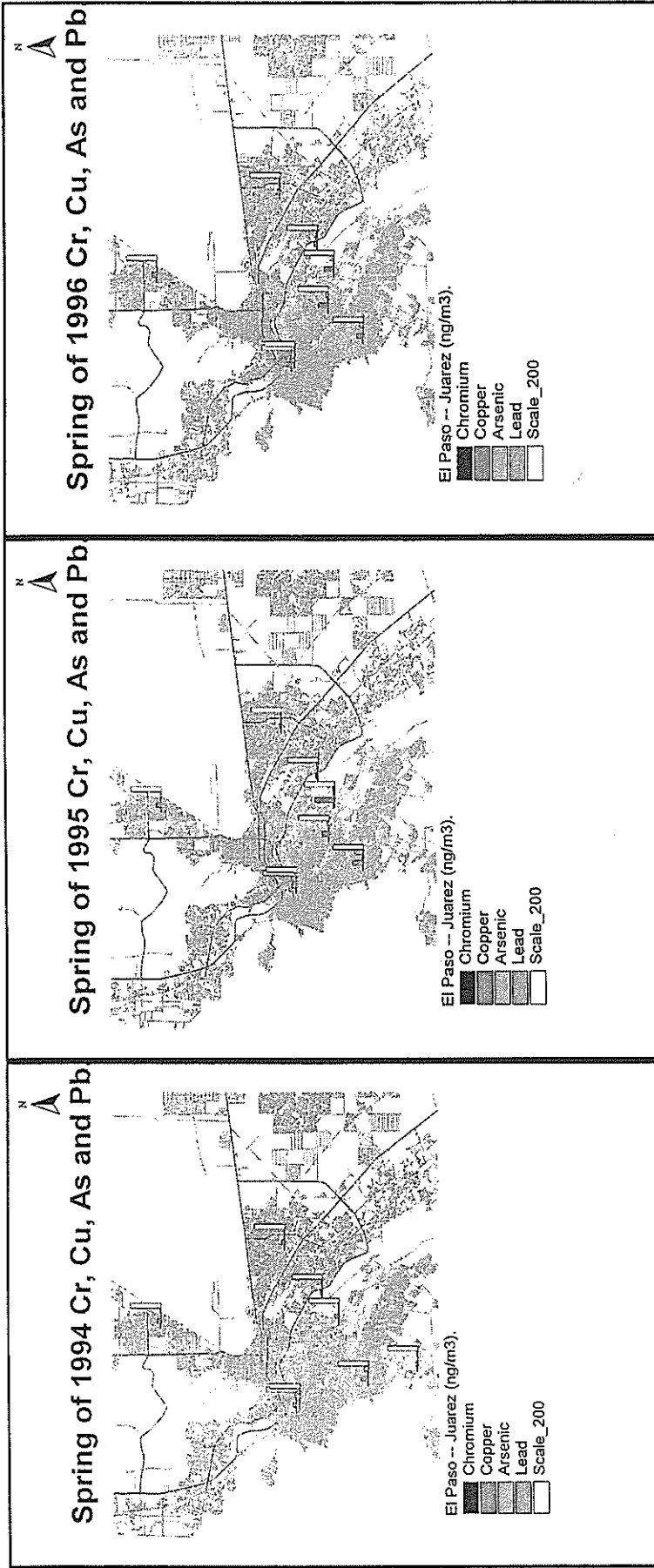


Fig. 3. Geographic map with concentrations (ng/m³) of Cr, Cu, As and Pb during a spring day of 1994, 1995 and 1996 in El Paso and Cd. Juarez.

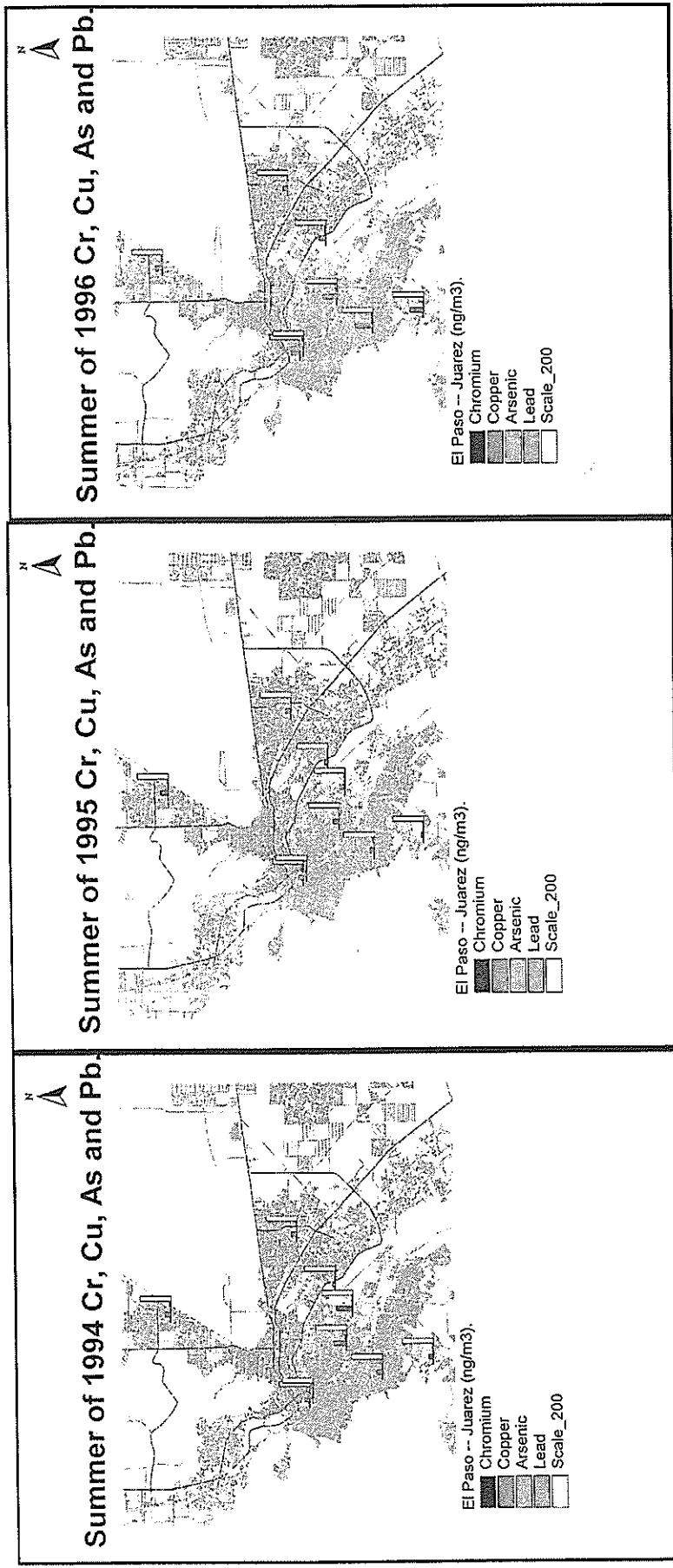


Fig. 4. Geographic map with concentrations (ng/m³) of Cr, Cu, As and Pb during a summer day of 1994, 1995 and 1996 in El Paso and Cd. Juarez.

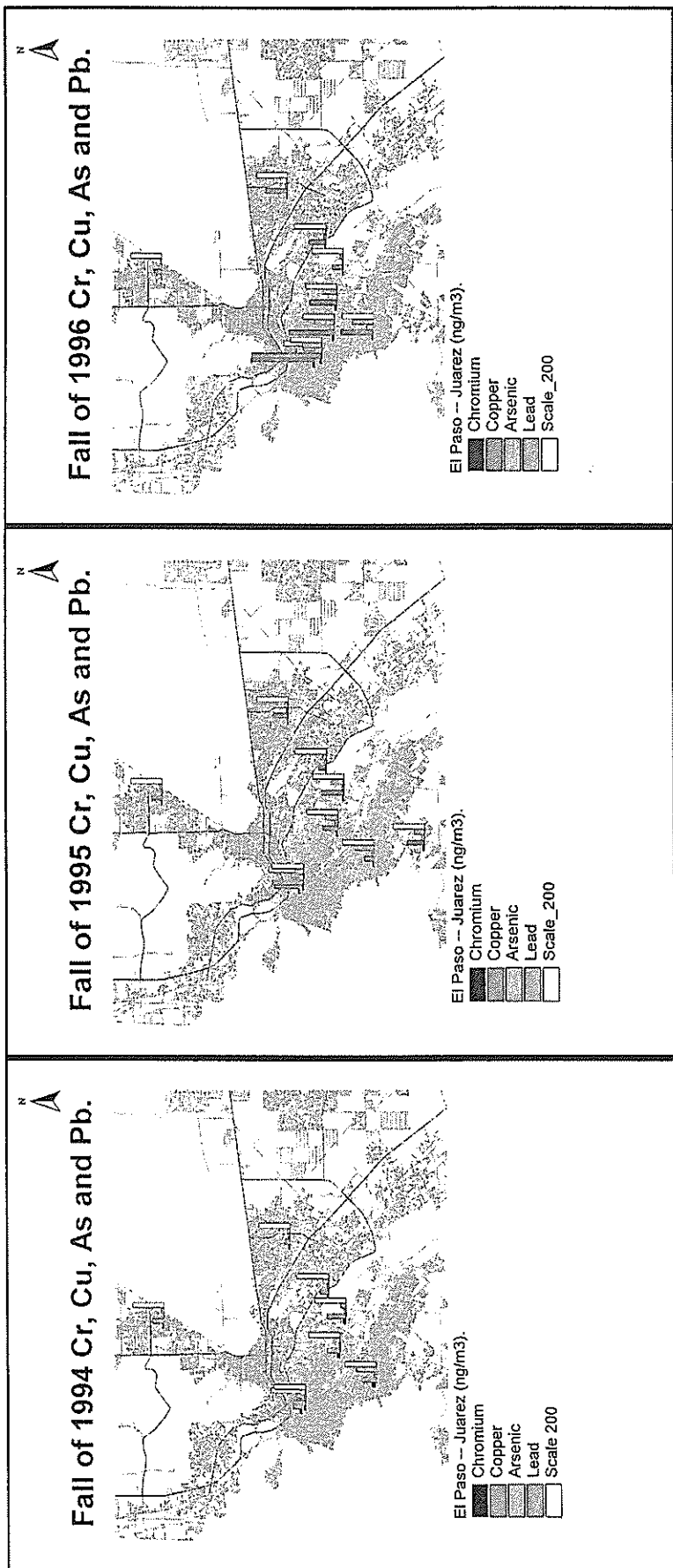


Fig. 5. Geographic map with concentrations (ng/m^3) of Cr, Cu, As and Pb during a fall day of 1994, 1995 and 1996 in El Paso and Cd. Juarez.

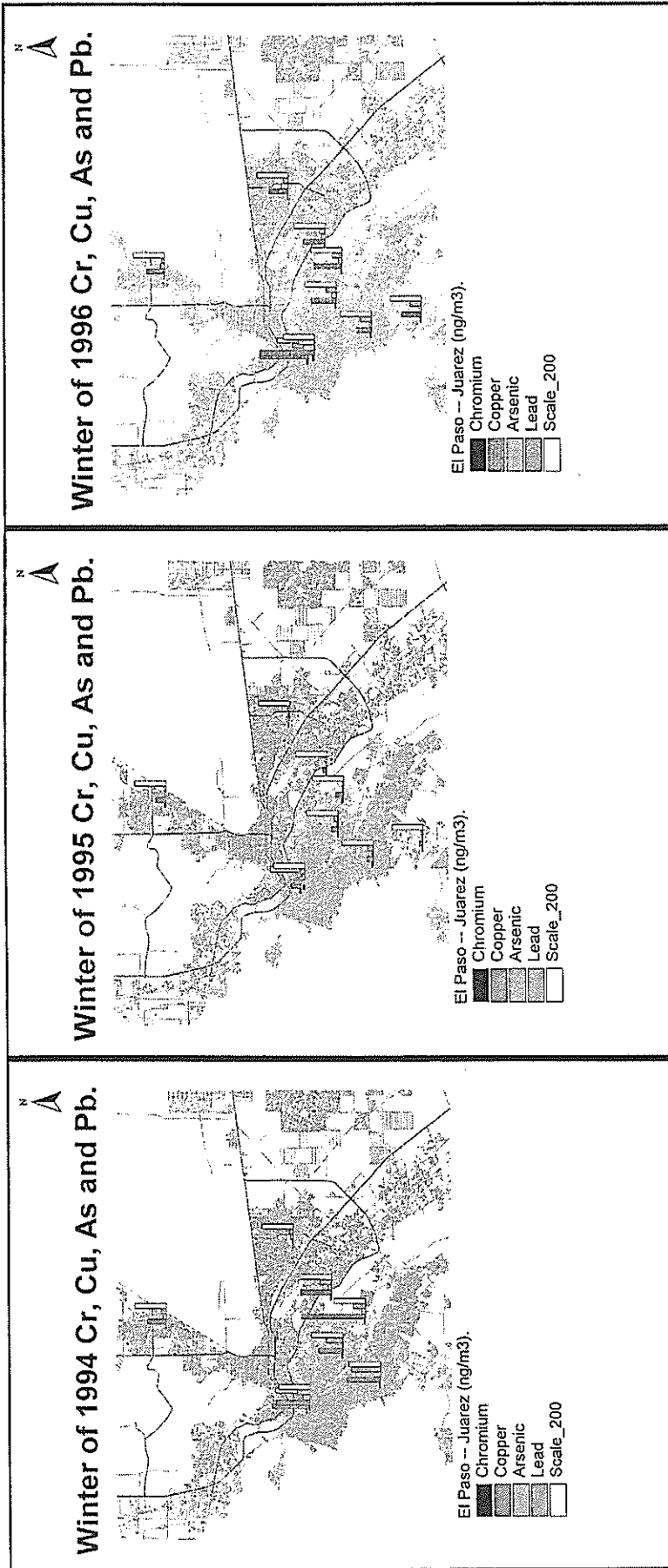


Fig. 6. Geographic map with concentrations (ng/m^3) of Cr, Cu, As and Pb during a winter day of 1994, 1995 and 1996 in El Paso and Cd. Juarez.

Table 2. Spring concentrations (ng/m³) for Cr, Cu, As and Pb for the years 1994, 1995, and 1996 in the El Paso-Juárez area.

SPRING												
ng/m ³	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
	Cr	Cr	Cr	Cu	Cu	Cu	As	As	As	Pb	Pb	Pb
Tillman	2	2	4	24	24	36	2	2	2	8	8	6
TillmanB	2	2	3	20	20	31	2	2	1	12	12	6
Riverside	2	2	5	12	12	20	1	1	8	7	7	7
Ivanhoe	3	3	3	19	19	17	0	0	3	3	3	3
Northeast	6	6	4	21	21	31	1	1	2	4	4	4
Tecno	3	3	3	40	40	69	1	1	2	4	4	27
Tecno2	4	4	2	28	28	67	1	1	2	4	4	23
Zenco	7	7	FNA	11	11	FNA	1	1	FNA	6	6	FNA
Pesta	FNA	FNA	3	FNA	FNA	65	FNA	FNA	4	FNA	FNA	13
Advance	6	6	5	50	50	41	3	3	4	26	26	22

Table 3. Summer concentrations (ng/m³) for Cr, Cu, As and Pb for the years 1994, 1995, and 1996 in the El Paso-Juárez area.

SUMMER	1994		1995		1996		1994		1995		1996		1994		1995		1996	
	Cr	Cr	Cr	Cr	Cr	Cr	Cu	Cu	Cu	Cu	Cu	Cu	As	As	As	Pb	Pb	Pb
Tillman	4	4	2	30	30	58	1	1	1	1	3	17	3	17	17	6	6	6
TillmanB	3	3	2	38	38	91	1	1	1	3	9	9	3	9	9	6	6	6
Riverside	4	4	2	16	16	42	0	0	0	7	4	4	7	4	4	5	5	5
Ivanhoe	5	5	1	37	37	31	0	0	0	7	4	4	7	4	4	4	4	4
Northeast	5	5	2	34	34	47	0	0	0	6	7	7	6	7	7	3	3	3
Tecno	2	2	FNA	65	65	FNA	0	0	0	FNA	3	3	FNA	3	3	FNA	FNA	FNA
Tecno2	2	2	FNA	103	103	FNA	1	1	1	FNA	6	6	FNA	6	6	FNA	FNA	FNA
Pesta	4	4	4	84	84	96	4	4	4	7	24	24	7	24	24	13	13	13
Zenco	3	3	6	30	30	88	1	1	1	5	7	7	5	7	7	30	30	30
Advance	3	3	3	38	38	116	1	1	1	3	13	13	3	13	13	7	7	7

Table 4. Fall concentrations (ng/m³) for Cr, Cu, As and Pb for the years 1994, 1995, and 1996 in the El Paso-Juárez area.

FALL															
ng/m ³	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
	Cr	Cr	Cr	Cu	Cu	Cu	As	As	As	Pb	Pb	Pb	Pb	Pb	Pb
Tillman	6	5	13	51	150	416	2	18	39	29	50	75			
TillmanB	3	6	10	55	184	457	1	18	39	26	47	122			
Riverside	3	4	6	50	46	108	1	8	6	32	22	16			
Ivanhoe	3	3	3	29	85	141	0	4	9	7	16	5			
Northeast	2	2	2	71	60	49	1	4	13	8	13	5			
Tecno	11	6	5	99	143	125	1	7	7	24	65	33			
Tecno2	11	6	2	118	133	66	1	7	3	26	73	16			
Pesta	15	10	13	79	89	174	2	14	53	34	71	90			
Zenco	FNA	7	FNA	FNA	98	FNA	FNA	14	FNA	FNA	56	FNA			
Advance	19	5	8	89	55	209	3	7	40	125	115	133			
20-30	FNA	FNA	8	FNA	FNA	291	FNA	FNA	25	FNA	FNA	121			

Table 5. Winter concentrations (ng/m³) for Cr, Cu, As and Pb for the years 1994, 1995, and 1996 in the El Paso-Juárez area.

WINTER	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
ng/m³	Cr	Cr	Cr	Cu	Cu	Cu	As	As	As	Pb	Pb	Pb
Tillman	5	11	11	227	62	315	46	10	66	85	29	98
TillmanB	5	7	13	221	64	357	42	9	69	78	27	103
Riverside	6	6	4	199	20	140	19	2	23	72	11	38
Ivanhoe	0	6	2	0	19	121	10	2	39	21	7	23
Northeast	2	8	2	116	59	114	15	6	20	28	10	17
Tecno	4	FNA	8	777	FNA	156	18	FNA	23	76	FNA	59
Tecno2	4	11	5	415	47	180	19	2	21	76	8	60
Pesta	5	3	6	156	35	163	13	3	25	105	22	62
Zenco	FNA	7	6	FNA	22	128	FNA	3	16	FNA	9	71
Advance	6	8	6	214	41	96	42	3	11	185	34	71

