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Geographic Information System Applied to Urban Aerosols in Altamira, Mexico

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ABSTRACT

Using the Emission Inventory of Tamaulipas State in Mexico, a Geographical Information System (GIS) methodology was developed for the municipality of Altamira to help in the identification of PM_{10} and metal emission sources considering the meteorological conditions from April to November 2005. The metal content in PM_{10} was analyzed for the first time in the industrial zone of Altamira, Tamaulipas Mexico. Particulate matter less than 10 µm of aerodynamic diameter was collected every six days in quartz microfibre filters with a high volume sampler (Andersen). 10 metals (Cd, Cr, Cu, Fe, Mn, Pb, Ni, Ti, V and Zn) were evaluated in this industrial zone using an ICP-OES. Metal content in PM_{10} was extracted from the filters according to the method USEPA IO-3.1. All the reagents and laboratory material were ultrapure and certified class "A". Despite the fact that Altamira atmosphere is influenced by many different kind of industries, PM_{10} and lead concentrations in Altamira did not exceed Mexican regulations during the studied period as they were always less than 120 µg/m^3 and 1.5 µg/m^3 in 24 hrs respectively. PM_{10} concentrations ranged from 23 and 92 µg/m^3. The highest concentrations of metals were showed by Fe, Mn and Ti with approximately 2.0, 0.6 and 0.3 µg/m^3 respectively. The presence of V, as well as Mn, suggest that a refinery located near the sampling zone is the main source for those metals.

Keywords. Heavy metals; PM_{10}, ICP-OES, GIS, Altamira, Industrial Zone

1 INTRODUCTION

It has been noted that the chemical composition of the particulate matter is very important because some species such as metals are toxic and are associated to anthropogenic particles[1]. Nowadays, toxicity and health effects of particles are determined by their size and chemical composition[1,2]. These health effects have been studied by epidemiological research and the accumulation of particles show swelling and lung damage. The main sources of particles could be vehicle emissions, dust and industries[3]. This study was carried out in an urban zone at the southern of Tamaulipas, Mexico, which is composed by Altamira, Tampico and Ciudad Madero. The industrial sector is placed mainly in Altamira with 23 petrochemical industries producing 4 millions of metric tons of plastic products, representing 30percent of the Mexican Petrochemical PIB, other important activities in this city are agriculture and livestock. An oil refinery is located in Madero City. The main activities in Ciudad Madero and Tampico are commerce and tourism. Since most of the industry is located in Altamira one monitoring station was located in this city. 22 percent of Tamaulipas' population (2,753 222) is located in Tampico, Madero City, and Altamira[4]. The total of vehicles in this zone is 119 342 (65 991 in Tampico, 11 695 in Altamira, and 41 656 in Ciudad Madero). Altamira is a coastal region with 30 Km of beach in the Gulf of Mexico; its territorial extension is near 1600 Km^2 where 400 Km^2 are rivers and lagoons; 100 Km^2 are used by industries and the port works actually with the 20 percent of its total capacity. 12 percent of the electric generation in Mexico is produced in Altamira by one thermoelectric and four gasoelectric industries.

Most of the environmental studies need great quantities of information that must be stored, processed, analyzed and presented in written or graphical form. The use of Geographical Information Systems (GIS) addresses and simplifies handling databases. In essence, GIS is a technological platform to pursue spatial analysis capable of providing coherent information storage, and allowing its upgrade and manipulation. The GIS facilitates maps, the design of cartographic models, and implementation of effective analysis tools, like signaling of corridors from a certain distance to a river or highway, interaction charts between two or more maps, calculation of slopes and display of measures among other things. All of this begins with the transformation or combination of diverse geographical data.

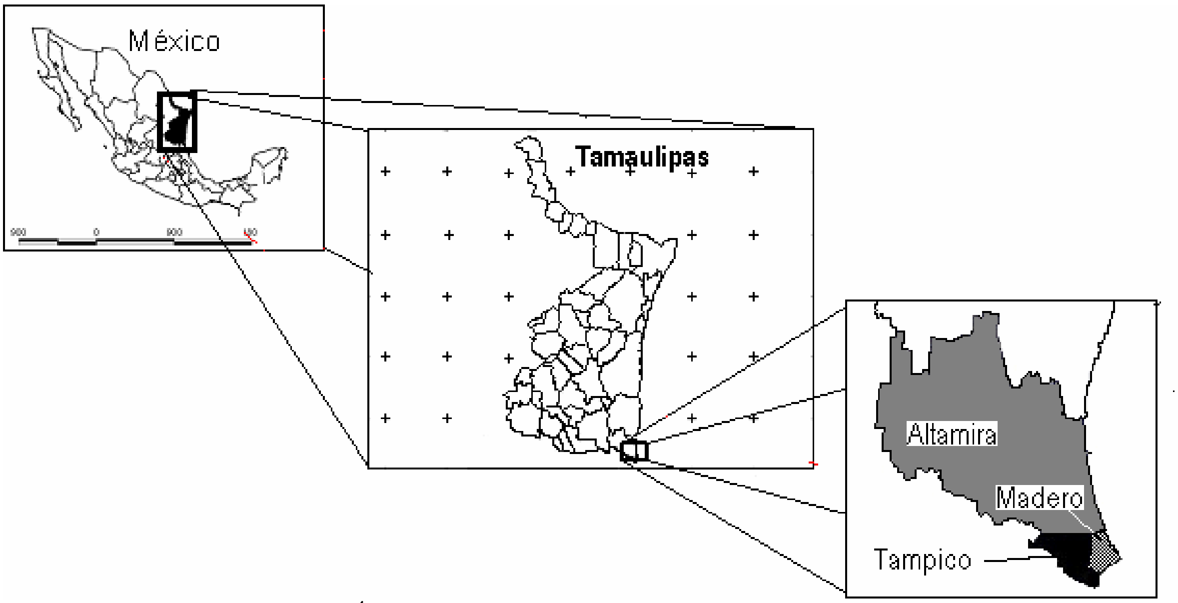
The goal of this work is to develop a methodology that allows the systematization and visualization of information through spatial analysis of aerosol atmospheric pollution sources, and their interaction with human population's exposure. In addition, PM_{10} and metal concentrations in a urban monitoring site in Altamira and Tampico are studied during an eleven-month period.

2 CHARACTERISTICS OF THE STUDIED AREA

The Altamira Municipality is located in the southern part of the State of Tamaulipas about 400 km from the USA border. The city of Altamira is located at 22°23´3" N and 97°55´0" W, at an approximate elevation of 20 meters above sea level. It is surrounded by lagoons as "El Chango", "El Conejo", "El Chairel", "Champayan", and the Panuco-Tamesi system river, one of the biggest rivers in Mexico that flows into the Gulf of Mexico.

Altamira is limited to the north by the Municipalities of Aldama and Gonzalez, to the south by Ciudad Madero and Tampico to the east by the sea, and to the west by Veracruz State (see figure 1). The PM_{10} is continuously collected in Altamira and Tampico every six days according to the monitoring schedule established by the Environmental Protection Agency of the United States (USEPA) and according to Mexican regulations adopted in 1994[5].

Figure 1. Tampico-Altamira-Ciudad Madero Metropolitan Area localization.



*Adapted from INEGI data[4]

3 METHODOLOGY

3.1 Population

The theme Population was built with information taken from the year 2000 INEGI's population census. (Table 1). Population and housing variables were considered for this theme, such as overall population, male and female, age strata, and housing types, among others. The items: roads, streets and services constituted the urban trace.

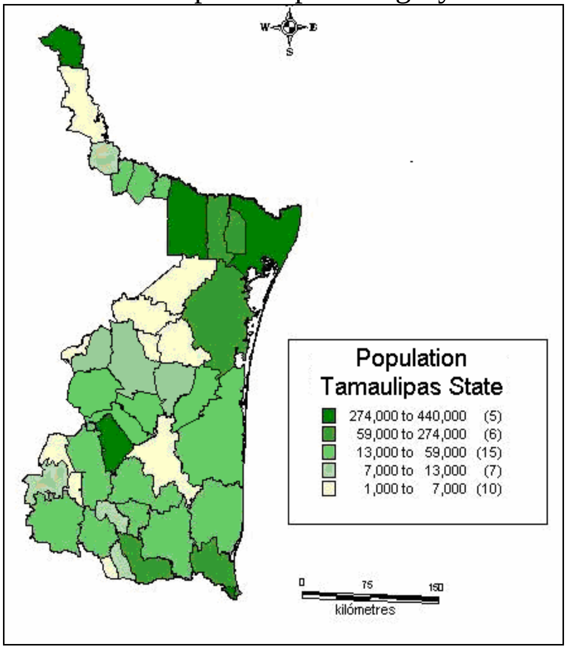
The total population of Tamaulipas (see figure 2) is 2 753 222 inhabitants distributed in 43 municipalities; 605,431 of these inhabitants are located in the studied metropolitan zone, where 49, 30 and 21 percent of them are located in Tampico, Madero City and Altamira, respectively.

Table 1. Summary of Population Database included in the GIS

	Key	**Total Population**	**Females**	**Males**	**houses**
1	Altamira	127 664	63 861	63 803	31 222
2	Tampico	295 442	154 396	141 046	76 753
3	Ciudad Madero	182 325	95 381	86 944	*47 810
4	Tamaulipas	2 753 222	1 393 348	1 359 874	683 068

Source. Adapted from 2000 INEGI database[4].

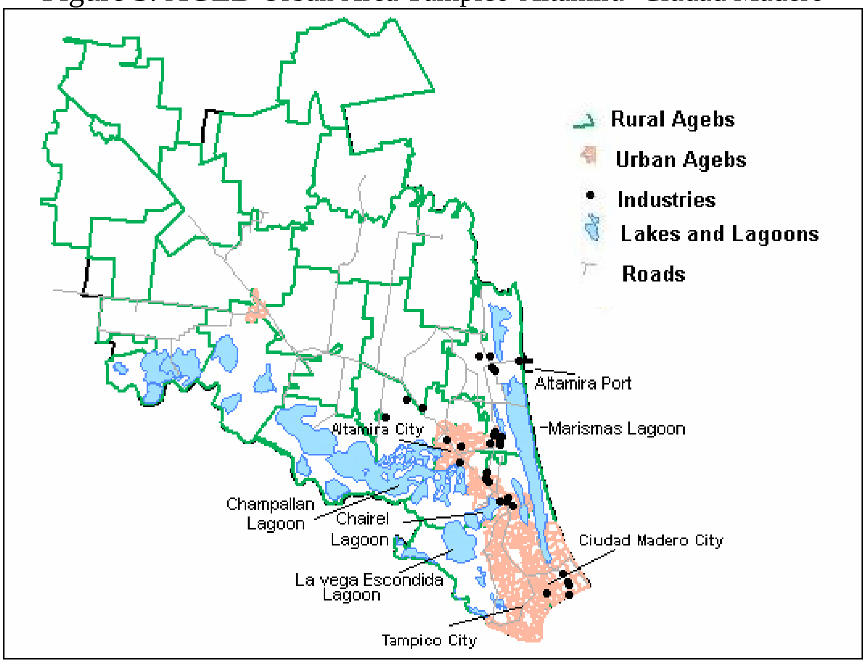
Figure 2. Total Population, at Tamaulipas State. The number in parenthesis indicate the municipalities per category.



3.2 *Geographical information*

The information layer known as AGEB[1] contains the limits of the 275 Basic Geostatistic Areas that compose the Urban Area of Tampico, Altamira and Ciudad Madero (figure 3). This layer was used as a fundamental graphical element to establish the reference for all the information layers that make up the system.

Figure 3. AGEB Urban Area Tampico-Altamira- Ciudad Madero



[1] AGEB: Basic Geostatistic Area (Spanish abbreviation)

3.3 Industrial Sources.

The industrial sources located in the area were digitized and georeferenced, and the bases were structured by theme charts that support the spatial analysis based on the selection of sites, which could help in the identification of metal sources. All the industrial information contained in this section and its corresponding register, is annually gathered by environmental authorities[6]. Each register contains general data about the industry (as localization, process description, raw materials and fuel consumption), regulated emission inventory among others.

3.4 Particulate monitoring and chemical analysis.

PM_{10} samples were collected during 24 hours at a flow rate of 1.0-1.1 m^3/min (1470 m^3 for 24 hours) every six days by an Andersen air sampler; located at a height of 13 m on the roof of CICATA (Applied Science and Advanced Technology Research Center) which is surrounded by two residential areas and by an industrial zone. The monitoring was carried out in 34 Whatman quartz microfibre filters which were stabilized in a controlled temperature and humidity room (25 ± 10°C and 50 ± 5 humidity) before and after sampling for gravimetric procedures. The concentrations of PM_{10} matter were corrected to standard conditions of 25°C and 760 mm Hg.

3.5 Chemical analysis.

To determine metal content in PM_{10}, 2.5 cm x 20 cm samples taken from the filter were digested with suprapure hydrochloric and nitric acid according to the microwave program established in the Method IO 3.1[6]. The solution obtained was filtered with Nylon 0.45 µm Millipore membranes and placed in sterile 15 ml polypropylene tubes. Metal concentrations in PM_{10} were determined by ICP-OES using a Thermo Jarrel Ash Equipment.

3.6 Emissions inventory

Table 2 shows the annual anthropogenic emissions of regulated pollutants in Tamaulipas State and the Mexican Republic compared with the emissions of Altamira[8], Ciudad Madero and Tampico in Mg, as well as the total in the urban area. It can be observed that the 70 percent of the SOx and 44 percent of the NOx generated in the Urban Zone are emitted by petrochemical industries located in Altamira. 78 percent of the VOCs, 64 percent of PM_{10} and 62 percent of $PM_{2.5}$ are generated in Ciudad Madero, where the oil refinery is placed. Mobile emissions come predominantly from Ciudad Madero and Tampico with 84 percent of CO.

Table 2. 1999 Emission inventory (Mg/year)

	NOx	SOx	VOC	CO	PM_{10}	$PM_{2.5}$	total Mg/year
Altamira	9 320	91 849	2 815	7 153	5 422	1 469	116 559
Ciudad Madero	5 826	38 953	29 544	19 215	8 641	2 815	102 179
Tampico	5 669	885	5 649	18 222	10 388	2 221	40 813
Total urban Area	20 814	131 687	38 008	44 591	24 451	6 504	259 551
Total Tamaulipas State	52 758	153 468	93 247	174 155	116559	29 344	590 187
Total Mexican Republic	1 469 153	2 894 086	2 603478	7 507 563	802 708	582 495	15 276 988

Source: Adapted from National Institute of Ecology, 2005[8].

4 RESULTS AND DISCUSSION

Figures 4 and 5 show the total PM_{10} and SO_2 emission in Tamaulipas. In can be observed that the particulate matter PM_{10} , as well as SO_2, are emitted principally in cities located on the border with United States and in the urban zone at the southern Tamaulipas. This is due to the location of industrial facilities in these cities.

Figure 4. PM_{10} emission per municipality in Tamaulipas

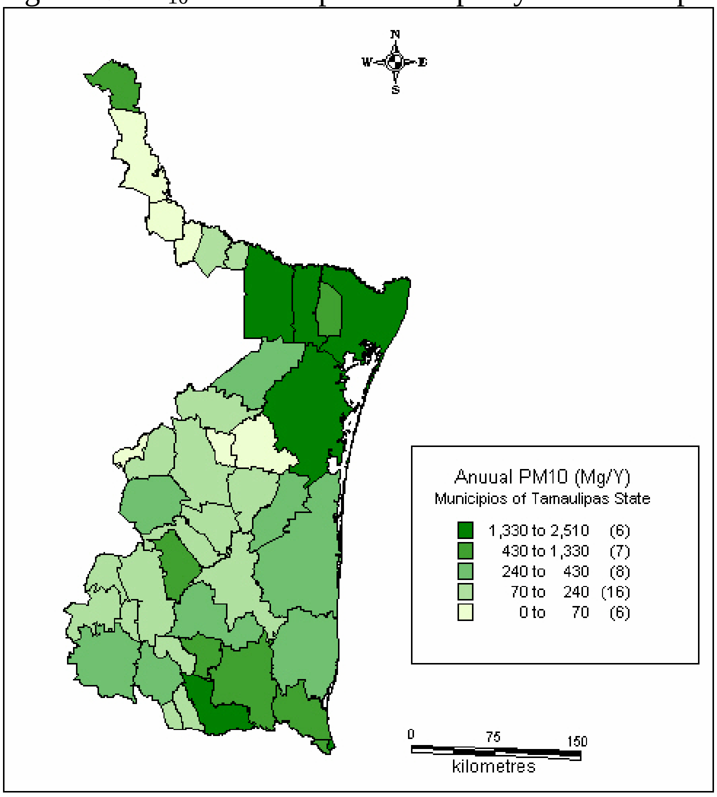


Figure 5. SO_2 emission per municipality in Tamaulipas

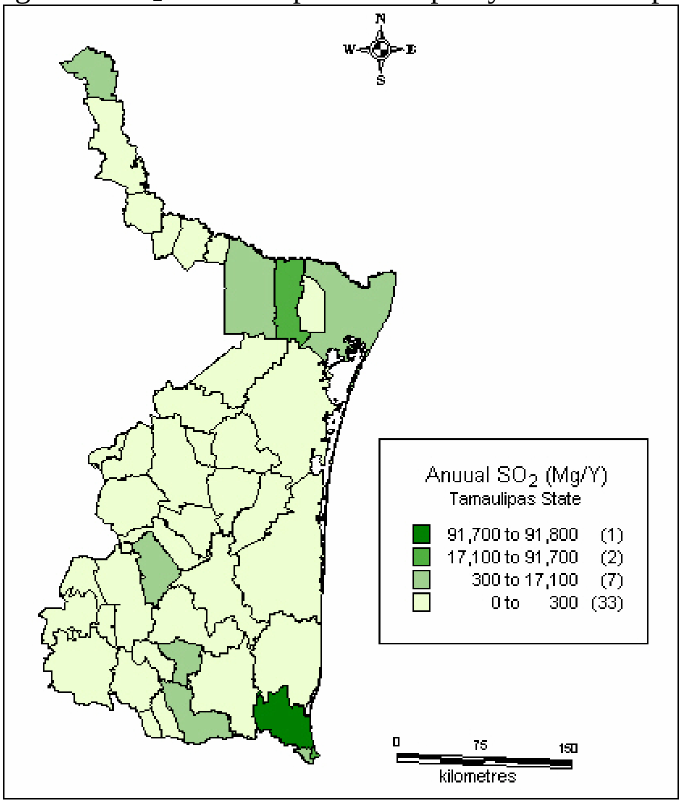
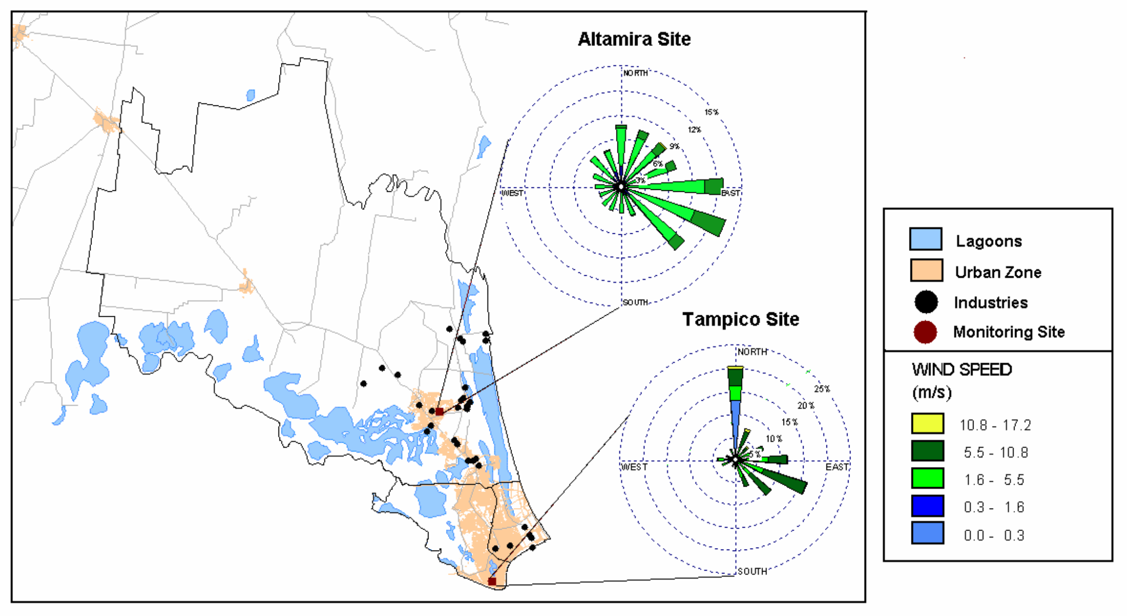


Figure 6 shows the localization of petrochemical industries in Altamira, an oil refinery in Ciudad Madero and the monitoring site at CICATA-IPN in Altamira. In addition, this figure shows the wind roses that represents wind speed and direction near the monitoring sites in Tampico and Altamira. The predominant wind direction in Altamira and Tampico is from ESE and N. Also, some wind from NE and W could be observed. The winds from ESE and E could cause that sand and emissions from some industries be conducted to Altamira monitoring site.

There are not significant PM and metal emission sources located to the ESE in Tampico, but the monitoring site in this city could be impacted by PM emissions from the industrial port of Altamira during winds coming from the N. According with these data, the population of Tampico and Altamira are situated downwind the industrial emissions, however some parameters as geographic features, high wind velocities and the predominant direction from ESE allow the dispersion of PM_{10}.

Figure 6. Urban, industrial and rural areas in the urban zone with the wind roses corresponding to the monitoring sites in Altamira and Tampico.



Tables 3 and 4 show the maximum, mean and minimum concentration of PM_{10} determined in Altamira and Tampico[9]. These concentrations did not exceed the Mexican Standard of 120 µg/m^3 in 24 hours during the studied period. The mean concentration of PM_{10} in Altamira was 53 µg/m^3, whereas in Tampico the concentration was around 50 percent lower with 24 µg/m^3.The maximum and minimum concentrations in Altamira were observed in April and December. In opposite, the maximum concentrations in Tampico were found in December and the minimum in June. Low concentrations in Tampico are due to the wind direction coming from the ESE, where there are no important particle sources and high concentrations are observed when tourism and traffic enhances in December. On the other hand, low concentrations in Altamira are observed when wind comes from N and NW where lagoons and valleys are situated, as well as during high precipitation periods. High concentration of particles in Altamira could be due to low precipitation periods in addition to the wind direction coming from industrial sources and geological material located to the SE and E.

Table 3. Basic Statistics of PM_{10} (µg/m^3) in Altamira.

Month	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	64	82	73	77	68	64	92	72	80	84	54
Mean	50	64	66	52	49	50	58	48	53	54	32
Minimum	23	44	54	35	27	35	23	21	30	27	6
Std Dev.	24	14	8	17	18	14	30	21	19	23	20

Table 4. Basic Statistics of PM_{10} (µg/m^3) in Tampico.

Month	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	26	31	34	30	18	23	28	32	27	27	47
Mean	23	26	24	20	16	17	23	21	24	22	41
Minimum	18	19	18	13	15	12	17	12	22	20	35
Std Dev.	4	5	9	6	2	4	5	7	2	3	9

Figures 7 and 8 show the metal content in PM_{10} in Altamira and Tampico from April to November.

During the studied period, Fe was the most abundant element in Altamira and Tampico and it could be mostly associated to geological sources. The next most abundant metals in Tampico were Mn and Zn with maximum concentrations of 1.27 and 0.80 $\mu g/m^3$, whereas in Altamira are Zn and Ti with maximum concentrations of 0.43 and 0.13 $\mu g/m^3$, respectively. The least abundant element in Tampico and Altamira, was Cd with maximum concentration of approximately 0.003 $\mu g/m^3$. The concentrations of Cr were comparable in Altamira and Tampico with 0.0043 and 0.0045 $\mu g/m^3$. The concentrations of Cu and V were almost two times higher in Altamira (with 0.0424 and 0.0253 $\mu g/m^3$) than in Tampico (with 0.0330 and 0.0167). The concentration of Ni in Tampico was 0.0043 $\mu g/m^3$ and 0.0028 $\mu g/m^3$ in Altamira.

Pb concentrations in Tampico and Altamira did not exceed the Mexican Standard of 1.5 $\mu g/m^3$. The maximum concentration of Pb was observed in Tampico with 0.1 $\mu g/m^3$. In general, the concentration of metals such as Cd, Cr, Cu, Zn and V associated to industrial activities[10,11,12] were higher in Altamira than in Tampico, because the industrial port is situated in Altamira. In addition, concentrations of Fe and Ti that are associated to geological sources[13] were higher in Altamira, probably due to geological source as sand. On the other hand, the presence of metals as Pb and Ni found in Tampico could be associated to vehicle emissions[10], since the traffic is higher than in Altamira. The high concentrations of Mn observed in Tampico may be associated to a ferromanganese industry[14] located to approximately 15 km to the SW of the monitoring site.

Figure 7. Metal concentrations in PM_{10} in Altamira

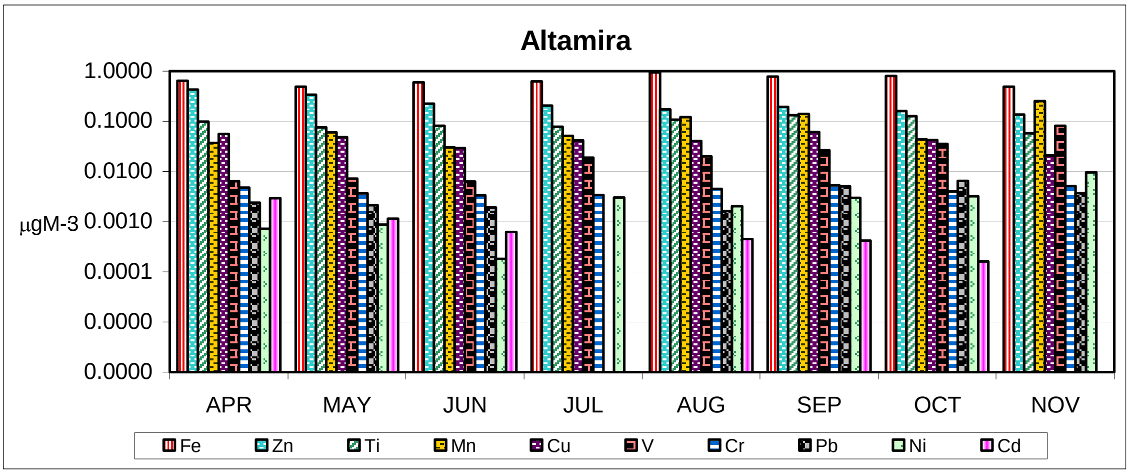
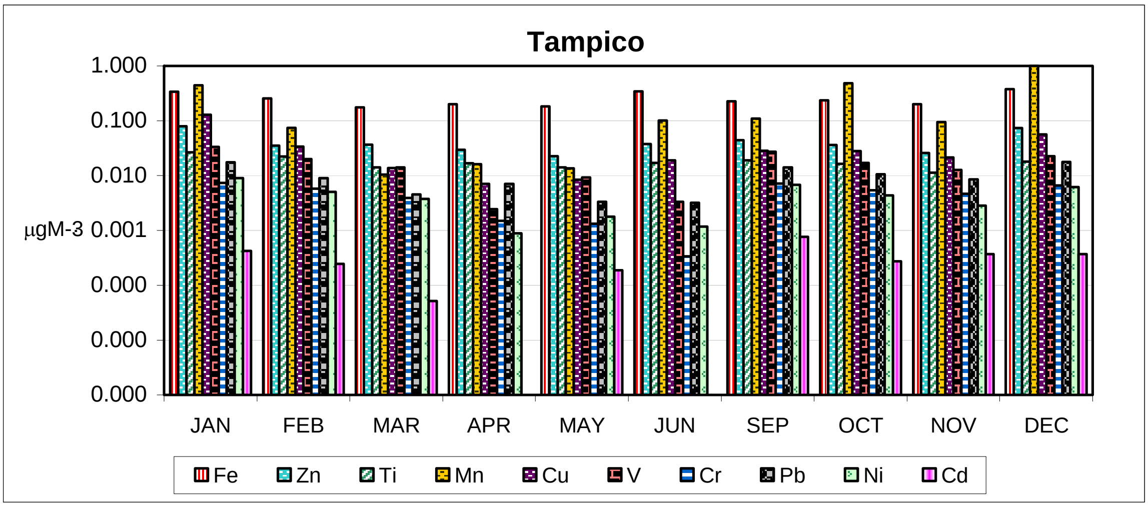


Figure 8. Metal concentration in PM_{10} in Tampico



5. CONCLUSIONS

The GIS developed methodology allowed the systematization and visualization of information. This methodology integrated the regionalization of areas to identify sources and mechanisms of pollutants fate, and their interaction with human population's exposure.

PM_{10} and lead concentrations in Altamira did not exceed Mexican regulations during the studied period. The mean concentration of PM_{10} in Altamira was 53 µg/m^3, whereas in Tampico the concentration was around 50 percent less than in Altamira. Other important metals in Tampico were Mn and Zn while in Altamira were Zn and Ti. The highest concentrations of metals in Altamira were showed by Fe, Mn and Ti with approximately 2.0, 0.6 and 0.3 µg/m^3 respectively. Despite the fact that Tampico is impacted by the industrial zone of Altamira, low concentrations were found due to the high wind speed, and that predominant wind direction comes from the ESE where no important particle sources are installed. Only during December when tourism and traffic enhances high concentrations of PM_{10} are observed.

The highest concentrations of PM_{10} are observed in Altamira when the wind direction comes from SE and E (industries and beach). Low concentrations of PM_{10} are observed in Altamira during raining periods and when wind comes from N and NW where lagoons and valleys are located.

The population of Tampico and Altamira are situated downwind the industrial emissions, however some parameters as geographic features, high wind velocities and the predominant direction from ESE allow the dispersion of PM_{10} and metals.

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