Mecánica Computacional Vol. XXIII, pp. 1787-1806
G.Buscaglia, E.Dari, O.Zamonsky (Eds.)
Bariloche, Argentina, November 2004

A GIS MODEL FOR URBAN AIR QUALITY ANALYSIS

S. Enrique Puliafito*, Miguel A. Gantuz, Carlos M. Puliafito

Universidad de Mendoza, Argentina
A. Villanueva 773, 5500, Mendoza, Argentina
Tel ++54 (0261) 4202017; epuliafito@frm.utn.edu.ar
* Research member of CONICET, now at Universidad Tecnológica Nacional

Keywords: urban air quality, geographical information system, atmospheric dispersion

Abstract: *Like many big urban centers, Mendoza, a city of about 900,000 inhabitants, has increasing air pollution mostly from mobile sources. To asses on its air quality, two main strategies have been developed: the setup of a network of monitoring stations and the development of a comprehensive model. Continuous monitoring and daily measurements of main pollutants had been performed since more than 10 years, at different sites, combined with several measuring campaigns. On the other side, a model, based on a geographical information system has been developed to evaluate the air quality derived from stationary and mobile sources. Once the model has been calibrated with the given measurements, the system is then used to test the compliance to local standard air quality, or to study the environmental impact of new industries or to determine the changing conditions when vehicle circulation is increased. This allows characterizing areas with potential increase in air pollution or improvement in air quality. It is also possible to compute different scenarios by changing basic information as traffic flow, or stack emission rates.*

1 INTRODUCTION

The city of Mendoza is located in western Argentina in an arid to semi-arid zone of low rainfall, as it will be described below. Its people has a clear oasis culture, where great care is given in managing its limited resources, especially water and space, and developing an appropriate habitat based on a steady effort. Environmental legislation enforcement has been very active in the area of pollution reduction and control, especially in the areas of atmospheric pollution by mobile sources; pollution by urban solid domestic residues; contamination by dangerous and special waste; atmospheric pollution due to stationary sources; industrial water pollution; contamination by oil exploitation; and contamination by mining exploitation. However, new regulations mandate the monitoring and tracking of numerous issues, introducing extra demands on agencies at the local government level.

Since the early 90, the University of Mendoza through its Institute for Environmental Research (IEMA), in cooperation with the Center for Environmental Research UFZ-Leipzig-Halle, and the Max-Planck Institut for Aeronomy MPAE-Lindau (Germany), among other local universities and research centers, have joined the effort of the public office, implementing a broad environmental research program. Relevant aspects of this program included research in the area of urban pollution monitoring [1,2,3,4,5] ecosystem modeling, environmental standards and legislation [6], health effects due to ambient air [7,8], and sustainable architecture.

The air in an urban area is influenced by many factors. They range from local meteorology and orography, natural and anthropogenic emissions; which sends to the atmosphere, among others, pollutants like Carbon monoxide, Oxides of Sulfur and nitrogen, photochemical oxidants and Hydrocarbons, and dust. The major source of man-made pollution comes typically from industry, commerce, domestic cooking and heating, and transportation activities. Urban environment is stressed by a number of common problems such us population, industrial and commercial growth, increasing energy and transportation demands. Worldwide, before 1990 most of the concern and control efforts was given to the industrial sources, but lately it was very clear that the major source for the degradation of the air quality was not any more factories, but the road vehicles, - buses, passengers cars, light and heavy duty trucks or motorcycles. Additionally concern has been given in the last decade to understand and evaluate the impact of such emissions on the population’s health.

In this article we will concentrate only with aspects related to the air pollution situation in the city of Mendoza, showing the modeling efforts performed by our Institute, aimed to contribute to local authorities to implement an effective air pollution control strategy. This air quality modeling segments includes: emission forecasting models to predict the monitoring measurements; study and forecast of wind patterns and transport models; and dispersion models to correlate emission with ground ambient concentrations in order to understand the contribution of each sources. With the exception of ozone, which is a secondary pollutant, the present models represent approximately the pollutant situation;

therefore it is possible to model NOx, CO and hydrocarbons based on the emission rate at the source.

Different approaches may be adopted to handle this big amount of information, depending on the available technology, skills and environmental programs. Moreover, this information needs to be handled not only in temporal data formats for some monitoring stations, but over a wide spatial distribution. For this reason, the actual efforts in improving the air quality in Mendoza are based on a Geographical Information System (GIS), which can meet the required needs. GIS is a computer based systems that helps to translate environmental science into policy by using relevant geographically located information, combined with algorithms, procedures and models that represent general scientific understanding. Data sets created and organized under GIS can be shared between various government entities and the public. A GIS application allows any user, department or agency to access common geographical data and made it easy for the public to browse the data, providing excellent software for development and analysis. Today, GIS is surely one of the most used software platform for planning all over the world. These features justify choosing GIS as an appropriate management tool for air pollution control.

2 MATERIALS AND METHODS

2.1 Meteorology and orography

The city of Mendoza, (33°S, 68°W, 750 m. a. N. s. l.), is located at the east side of the Andes Mountains in western Argentina. The Cordillera close to Mendoza, reaches an average height of 5,000 m with peaks up to 7,000 m. This natural barrier influences the meteorological conditions determining a strong dependence in the air pollution situation. As it was said, the region is characterized by its low precipitations: 120 to 400 mm/a, (mean 230 mm/a), which occurs specially during the summer months (November to March). Only 3% of the total province territory (250,000 km^2) is irrigated by five main rivers with annual modules less than 50 m^3, conforming three main oases. Almost 70% of the population is concentrated in the northern oasis, reaching the Mendoza metropolitan area approximate 900,000 inhabitants.

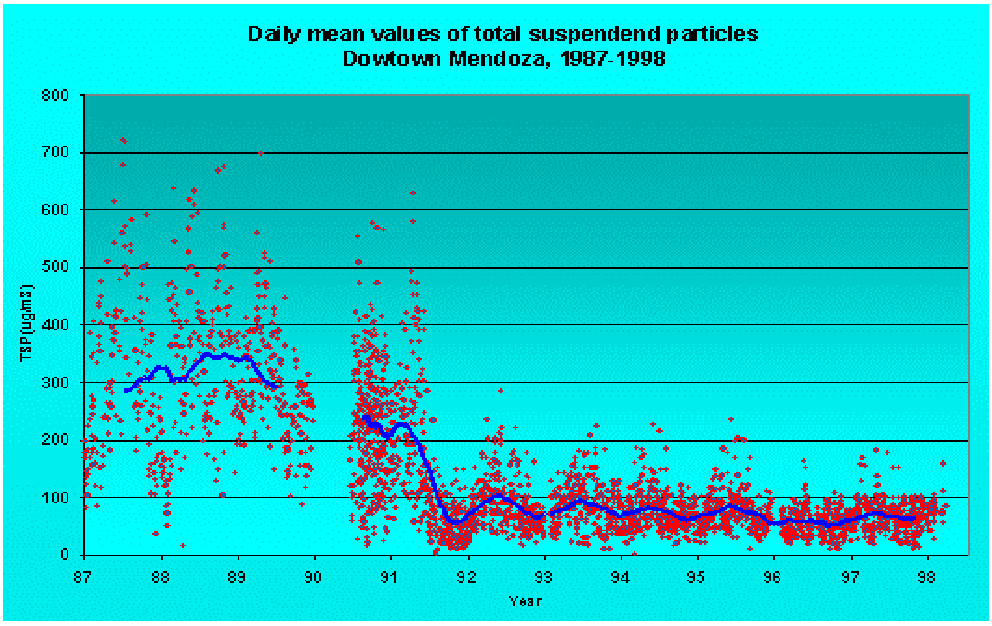
Due to its closeness to the mountains, Zonda winds similar to Föhn or Chinook winds, prevail in the higher layers mostly during the winter months (May to October) with high probability of frost, which contributes to a higher degree of pollution due to the occurrence of strong thermal inversion layers. The mean wind intensity is around 2 m/s, with mostly calm days (< 0.5 m/s) 35%, and predominant wind from S 13%, NE and W 12%, SW 10%, SE 8 %. Low relative humidity (50%), low incidences of fog and few days with covered skies (65-75 days/annum). The solar global radiation varies from 270 MJ/m^2 in winter to 780 MJ/m^2 in summer, with annual mean daily heliophany of 7.9 hours. The climate can be classified according to the Köeppen scale as BWakw: dry dessert, with mean temperature of the hottest month > 22°C, cold and dry winter with mean temperature below 18°C. The area presents low relative humidity (50%), low incidences of fog and few days with covered skies (65-75 days/annum). Another important feature for the description of the air pollution is the day-night variation, characterized by a typical valley-mountain circulation. From the first hours after sunset to early hours after sunrise, there is a clear wind flow from WSW, while in daylight hours the circulation is ENE. Strong solar heating on the valley side causes an up-slope wind flow at daytime (ENE). At night due to rapid radiational cooling on the valley slope, the circulation switches over causing the air masses to move down the mountain from WSW. This strong night cooling and day heating produces an important variation in mixing heights and inversion layers [1,2] .

2.2. Monitoring and sampling

Ambient concentration measurements of main pollutants have been monitored since 1970 in the metropolitan area of Mendoza by the Ministry of Environment and Public Works through its Direction for Environmental Control. In the urban area of Mendoza, around 15 stations monitors daily mean values of Total Suspended Particles (TSP) - by filter capture and reflectometry-, daily mean values of nitrogen oxides NOx -by colorimetric Griess-Saltzmann, and once a week 24 h mean values of lead Pb -by colorimetric ditozone-, and sulfur dioxide SO_2 -by colorimetric West and Gacke modified by Pate-. Also, our Institute IEMA, measures since 1995, black carbon and PAH poliaromatic compounds (Aethalometer GIV reflectometry), surface ozone (O_3), nitrogen oxides (NOx), carbon monoxide (CO), using a set of Horiba instruments (series APO350E for O_3 and APN360 for NOx and CO) and meteorological parameters, including solar global radiation. Besides the mentioned monitoring data, paper filter samples of particulate matter have been collected using a high volume pump at several measuring points. At the beginning of the project, few organized information was available over the emission of the fixed sources, thus it was necessary to set up an emission inventory of the main sources. These forms contain relevant information on type of fuel, yearly consumption, physical data of boilers, chimneys and emission measurements if available. Additionally various stack measurements were performed by independent consultants using an isokinetic stack samplers, following U.S. EPA Standard Methods.

2.3 Patterns of the airborne pollutants

The described meteorological and orographic conditions of the city, together with man's activity produce a characteristic air pollution pattern. A detailed analysis of the gathered ambient data shows several well define cycles. A main cycle is the seasonal variation (winter-summer), with higher values in winter and lower values in summer. Figure 1 shows monthly mean values of daily measurements of total suspended particles, monitored at the downtown area.



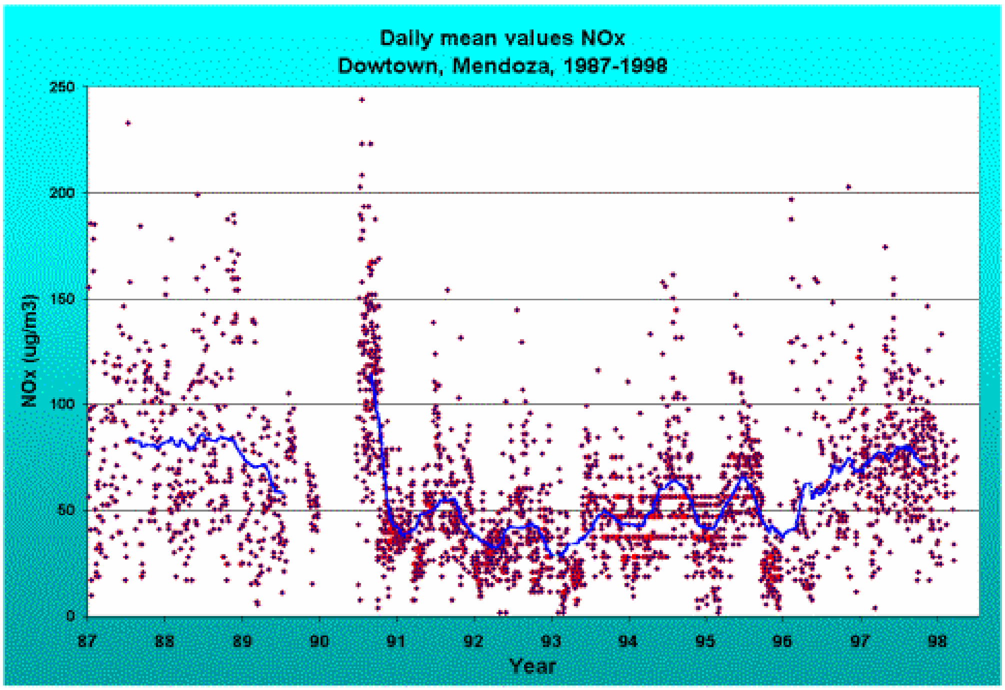


Figure 1: Daily mean values of total suspended particles (top) and NOx (down) at a downtown monitoring station. Blue line represents a 180 days running mean value.

This cycle is directly coupled to the meteorological conditions above described, namely calm winds, few precipitations and high occurrences of low inversion layers in winter. Seldom polar fronts from SE bring snowfalls to mountain and valley, breaking the accumulation cycle of air pollution. Another clear cycle is the day-night variation, characterized by a typical valley-mountain circulation as mentioned above

Figure 2 shows a typical day, with solar radiation, wind direction, surface ozone (O3), carbon monoxide (CO), and nitrogen oxides (NOx) measurements, monitored at the IEMA Institute. This graphic shows a strong traffic related emission, where it can be clearly seen the beginning of normal day activities from 7 to 9 am and back-to-home rush hour after 8 pm. It may also be noted; that despite in Mendoza there is an important flux of back to home traffic at noontime, mainly for lunch and because of end of school activities, the vehicle pollution is not heavily shown in the ambient concentrations values. This is an indication of the high convective dispersion present during midday. Note that Mendoza has a very dry (low humidity) climate, and then there is less heat exchange due to water vapor. Analyzing the monitoring data, it is possible to distinguish a typical weekly cycle, which confirms the relevance of mobile sources emissions in the air quality of Mendoza.

Figure 3 shows the annual daily mean values for TSP and NOx according to the day of week, from a data series of several years taken at one of the fixed monitoring station. So, it can bee seen that from Monday through Thursday the values are very similar, Friday is lower, and a strong decrease is present on weekend days.

2.4 Geographical Information System

GIS is a computer based system for capturing, storing, checking and manipulating data that are spatially referenced. For this study we used the ArcView® application due to its relative user friendliness and its wide use by local authorities and many research institutes. In our study, industries and monitoring sites are examples of point shapes, which correspond to records in the respective database. In each of this record, information regarding time series of monthly, annual mean values of ambient concentration is associated to the monitoring site database. Stack dimensions, emission rates and coordinates are associated to the industry database. In the GIS system, each street is represented by a segment corresponding to a record in the database. We have characterized streets according to three hierarchies: a) primary or main city access and inter county freeway; b) secondary or intra county roads; and c) tertiary or residential streets. The hierarchies had been selected according to traffic intensity, hourly variation, street width, dominant use, such as: private or public transport; light or heavy duty; commercial or residential; and other urban criteria. Streets axis, number and emission of vehicles are included in records of line shape type database. Each of these segments also includes length, street type, and county and so on. Several other indicators such as inhabitants per car use, inhabitant's growth rate, main city attractors, and a mobility source-destination public survey, have been used to complement the knowledge of the city mobility.

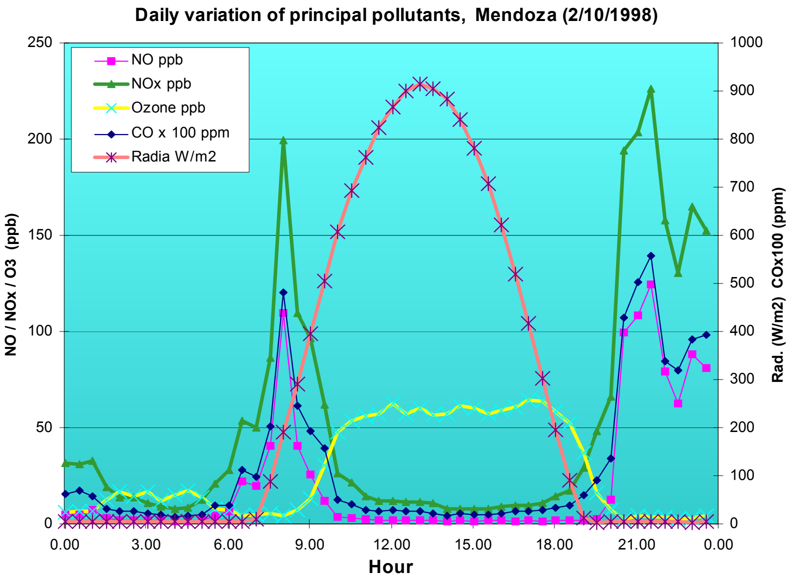


Figure 2: Typical daily variation of global solar radiation, and main pollutants monitored at the IEMA Institute, sited in Benegas, Mendoza. NOx: green line (ppb); solar radiation: orange with asterics (W/m^2); ozone: yelow line (ppb); CO: blue line with dots (x100 ppm).

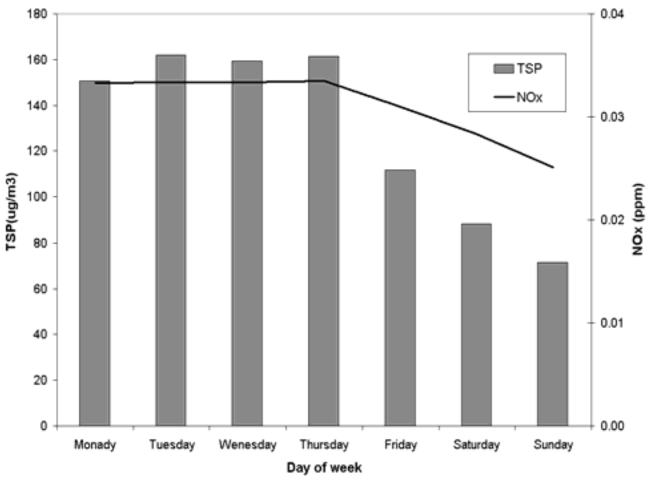


Figure 3: Annual mean values of TSP and NOx in μg/m^3 as a function of the day of the week measured at downtown area in Mendoza.

2.5 Calculation of industrial emissions

To treat the stationary sources, the model calls the program ISC3 (EPA: U.S. Environmental Protection Agency) that calculates the ambient concentration for multiple industrial sources at a receptor grid. As input for the ISC3 program we used the data of the prepared emission inventory: stack dimensions, output stack temperature, emission flow and velocity, source relative position and so on. The dispersion program needs also as input the local meteorological data from the monitoring stations. The output of this program is then calculated for each cell of the area under study. These concentrations are organized as a raster shape database inside the GIS system.

It is important to note, that the Gaussian dispersion models and the available wind data have certain limitations, which can be summarized as: a) the dispersion models suppose linearity between source emission and ambient concentration values at the receptors when enough averaging data are present; the minimum significant correlation is one-hour average; b) the model does not consider chemical combination, that is, the gases and particulate matter are considered inert, and the range leeward must not exceed 25 km; c) most of the anemometers record wind in 16 sectors of 22.5° degrees each, where an hourly mean value indicates the most frequent direction (mode); d) local micro dynamic at the receptor, due to the influence of trees, buildings, etc. are normally not considered. Despite these limitations, the calculations represent adequately daily, monthly and annually mean values, and are suitable for compliance with the air quality standards. The ambient concentration at a particular cell located at coordinates (x,y,z) from a fixed point source is generally calculated using a bidimensional Gaussian plume moving in the wind direction x. At ground level ($z=0$) the concentration C(g/m^3) is:

$$C(x,y,0)=\frac{Q}{u}\frac{1}{\pi\sigma_y\sigma_z}exp(-\frac{H^2}{2\sigma_z^2})exp(-\frac{y^2}{2\sigma_y^2}) \tag{1}$$

Where Q (g/m.s) is the emission rate of the source, H(m) is the effective stack height, y is the distance transversal to the wind direction in the horizontal plane, z is the altitude above ground, and u(m/s) is the wind speed. The lateral and vertical dispersion coefficients σ_x σ_y (m) depend on the stability class (and indirectly on the wind speed) and increase with increasing distance to the source x. The equation is well described in many books [9,10].

2.6 Calculation of the vehicle emissions

Two complementary approaches are generally proposed to estimate the emissions from road vehicles: the top-down approach or the bottom-up approach. The selection of one of these methods will depend on the availability of the main input data and the desired spatial and temporal resolution. In the top-down approach, the total annual emission from mobile sources is calculated using the number of road vehicles actually running for a given region. At any time and street, the vehicle flux is estimated through indirect information as population density, structure of the automotive park, fuel consumption, and number of cars per inhabitants. Three other estimation should be also considered, i.e., the average speed; the annual mean traveled distance; and the annual emission factors, normally based on fuel consumption. This information has acceptable spatial distribution, but a poor temporal resolution, usually on an annual base. To estimate the emissions from road vehicles in the bottom-up approach, traffic counting and speed recording in many streets are required. Normally this has a high temporal resolution (an hourly base) but poor spatial resolution. Also it is convenient to determine the vehicle fleet distribution according to power, size, fuel, and typical vehicle use. It is clear, then, that this approach requires high data density. To calculate the total emissions, it is necessary to estimate, average emission factors and fuel consumption for each vehicle category together with the mean traveled distances. Usually this latter approach is selected in urban areas when the information is available. Although the bottom-up design seems to be more accurate, the randomness of the involved variables washes out the accuracy of the detailed information. To compare both approaches it is necessary to calculate the total annual emissions on the same temporal scale and for a given region. After doing this, one must check for fuel consumption, number of total traveled distances per vehicle, etc. The advantage in using GIS is that most of the gathered or estimated information can be geographically distributed, simplifying the association with temporal data.

In this study, the bottom-up scheme was selected and downloaded to the GIS system. Traffic counting in main streets, average driving speed, and used emission factors, were recorded and grouped for different fuel and vehicle types. Also, this information was cross checked using a top-down methodology. In this case, relevant information from public registers and surveys was obtained: the structure of the automotive park, the average traveled distances the fuel consumption, the inhabitant's density, car per inhabitants, etc. The emission information from the vehicle factories and relevant international regulations and legislations was also gathered[11].

The emission factor e(g/km) due to street vehicles belonging to a group i is expressed as the mass of pollutant per unit length as a function of the traveled speed v. The total pollutant q for each street (or segment) with traffic flow n (veh/h) belonging to I vehicular groups is calculated as:

$$q = \sum_{I} \frac{p_i}{100} e_i(v).n_i \tag{2}$$

Where p is the percentage of vehicular group i with respect to the total flow. As emission factors we used Tables 8.1 to 8.3 of the Emission Inventory Guidebook[12]. Table 1 shows typical values of the emission factors used for Mendoza. Primary streets ambient concentrations, where the roads present no obstacles to dispersion, are treated as a line source using a Gaussian dispersion model. Small flux residential streets (tertiary) are considered as area sources, and for downtown streets a canyon plume box model is used. These ambient concentrations C (μg/m^3) may be calculated as [13]:

$$C = a\left[\frac{q/3.6}{W(u+0.5)}\right] * F + bT + dH \tag{3}$$

Where a is a constant ≈7, q is given in g/(km.h), u is the wind speed (m/s) at roof level, F is a shape factor depending on the wind direction, W is the street width (m), T is the ambient temperature (in Celsius) and H is the mixing height (m); b and d are the regression coefficients.
The total emissions of air pollutants from vehicles, using the top-down approach, for a given area, and for an (yearly) average period, it is characterized by three main factors:

$$E = N \times e \times l \tag{4}$$

Where E (g/unit time) is the total emission in the time considered, N is the number of average circulating vehicles in the period, e is the specific average emission factor measured in g/km per vehicles, and l is the mean traveled distance in km. The emission factor is an empirical function of the fuel consumption, the speed and age of the vehicle. This information is useful to understand the problems associated with road transport: i) The number of vehicles N: the monitoring data show clearly a raise of nitrogen associated to an increase in the automotive park. A reduction in N may be interpreted not only in a reduction of number of vehicles, but better as a decrease in the number of daily trips.

Table 1: Example of emission factors in g/km for1999 for gasoline and diesel fuels for given vehicle speed.

Speed	TSP		NOx		HC		CO	
	G	D	G	D	G	D	G	D
12 km/h	1.10	2.50	1.50	1.40	5.40	4.50	58.70	6.60
23 km/h	0.90	2.30	1.30	1.20	3.45	2.55	38.90	4.20
40 km/h	0.80	2.20	1.20	1.10	2.35	1.55	27.50	2.80
60 km/h	0.80	2.20	1.20	1.10	1.75	1.10	21.30	2.10

TSP: Total suspended particles, NOx Nitrogen oxides, HC: hydrocarbons, CO carbon monoxide, G: Gasoline, D: Diesel.

Some logical implications to reduce the effective number of road vehicles are: a) to promote and improve public transportation; b) to increase the occupational rate of vehicles; c) to improve the coordination of time schedules, in order to balance the transport demands. ii) The emission factor e**:** This factor is directly related to the available technology standard, and the driving style. A reduction in e is slowly incorporated as new vehicles with better technology replace old vehicles, but since Mendoza is situated in an arid area, the average age vehicle is >10 years, and mostly not fitted with catalytic converter. Regular technical vehicle inspection and carefully planning of new avenues and traffic light synchronization may contribute to reduce the effective emission factor. iii) The driving distance l: To reduce l it is necessary to coordinate with city urban planners and decision makers some of the following aspects: a) decentralization of the public offices, which actually are very much concentrated in the downtown area; b) improvement of public educational activities at the peripheral areas; c) decentralization of shopping centers and bank offices. This latter has only been done by market needs, but unfortunately with not enough urban planning. Decentralization will promote and strength the local communities, will increase their cultural, educational and commercial offers, and certainly will contribute to reduce the needs of transportation. At present, the increase of Internet use may contribute positively to increase the efficiency in the transportation of goods.

2.7 Description of the model

The diagram in figure 4 represents the principal steps of the used model, which will be quickly described. First, it is necessary to gather the necessary source information such as: industry inventory, number of vehicle, street types; secondly, emission factors for both stationary and mobile sources should be measured or estimated. As a next, an emission pattern can be prepared, which will be computed and stored as either line shape (vehicle) or grid shape (industry) databases. To handle this information, the city has been divided into cells of 350 m x 350 m, where each cell represents a record in the database. This database contains information such as, coordinates of the receptor grid and ambient concentration for the main pollutants. For areas close to the industrial sources smaller grid of 100m x 100m are also available.

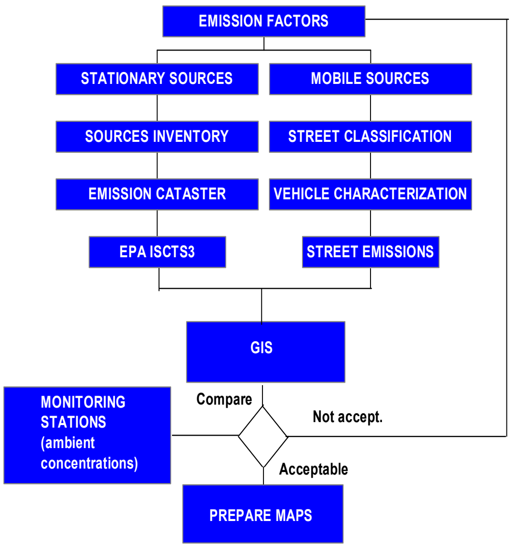


Figure 4: Block diagram of the model.

In order to compare, at the street level, both data bases type, the pollutant coming from the industrial sources are added as a background concentration to the ambient concentrations of pollutants provided by the mobile source calculations. Once the model is calibrated, which has been done through several measuring campaigns[14], and then it is possible to use the model to simulate different scenarios, and prepare the output maps.

3 RESULTS

3.1 Model outputs

In the Mendoza area, it is possible to identify three main groups of stationary sources: a) an oil refinery and a petrochemical industry as main emitters of particles and SO_2; b) an energy power plant, mainly based on natural gas, with important NOx emissions; and c) two medium companies responsible for black smoke fumes. These latter sources produce metal and ferrous alloy and coal briquettes for heating. Each of these two industries has also open piles for the storage of iron and coal respectively, which were included in the dispersion model as area sources of 400 x 400 m each. The geographical location of industrial sources was positioned using a GPS receiver. To calibrate the industrial source emissions, several monitoring campaigns were performed close to an industrial complex situated at the SW of the city. In these campaigns, continuously (3-min sampling) NOx, CO, O_3, black carbon, temperature, wind speed, and pressure at different sites were taken. The black carbon data were compared with a gravimetric method, by taking several samples on a paper filter (48 hours each) using a high vacuum pump. The data were computed using equation (1) and then compared with the measured values at the test monitoring sites, showing a correlation factor of 0.85.

After the calibration process has concluded, it is possible to study the spatial distribution of the ambient concentration for the entire city. As an example of these model outputs, two years (1997-98) of meteorological data, has been calculated. Different temporal integration are possible, but normally, the following averaging conditions are usually computed: maximum hourly values, 24 h, 30 days, and annual mean values. The next figures show several types of outputs, which illustrates the calculated conditions. Figure 5 shows a map with the spatial distribution of the street hierarchy and figure 6 displays the respective average traffic flow for each street. Based in this information, it is possible to establish a pollutant emission inventory for the mobile sources. Figure 7 plots, for example, the emission pattern for total suspended particulate matter. Figure 8 shows the calculated ambient concentration for NOx produced by the mobile sources, where it is possible to recognize areas with a mayor impact on the air quality, especially close to the central business area.

At the south industrial area, the ferrous alloy and the coal burning processes are the main emitter, especially because they function with out any filtering device to their dust emissions. Maximum hourly immission values may reach 1500 $\mu g/m^3$ and more than 200 $\mu g/m^3$ daily mean values close to the sources. Ten kilometers away, at a residential part of the city annual mean values of 30 to 40 $\mu g/m^3$ can be obtained, especially during the winter months.

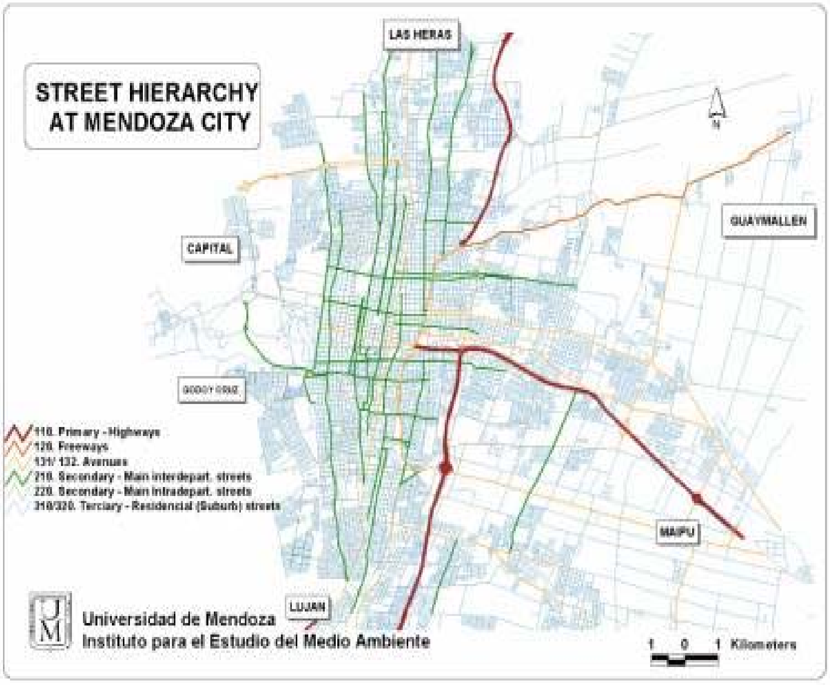


Figure 5: Street hierarchy for the Mendoza metropolitan area.

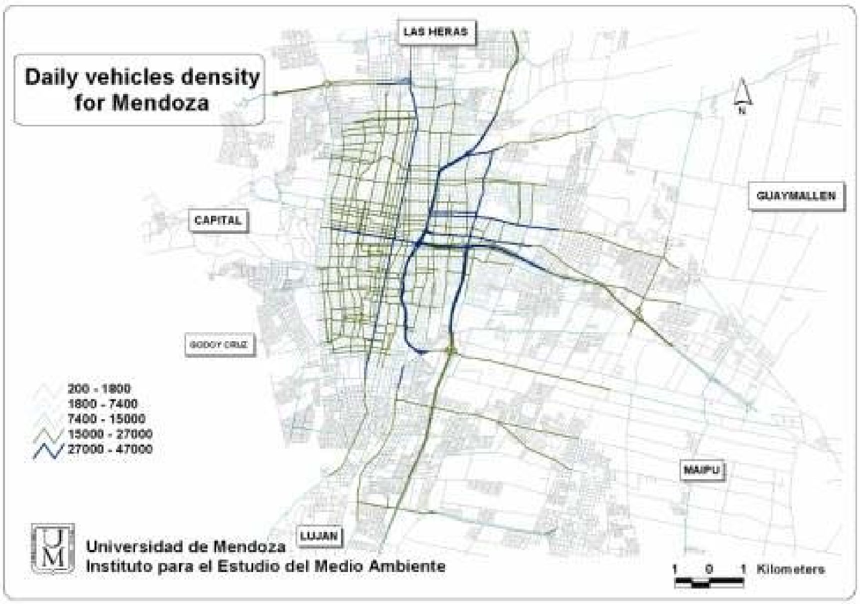


Figure 6: Average traffic flow in the city metropolitan area.

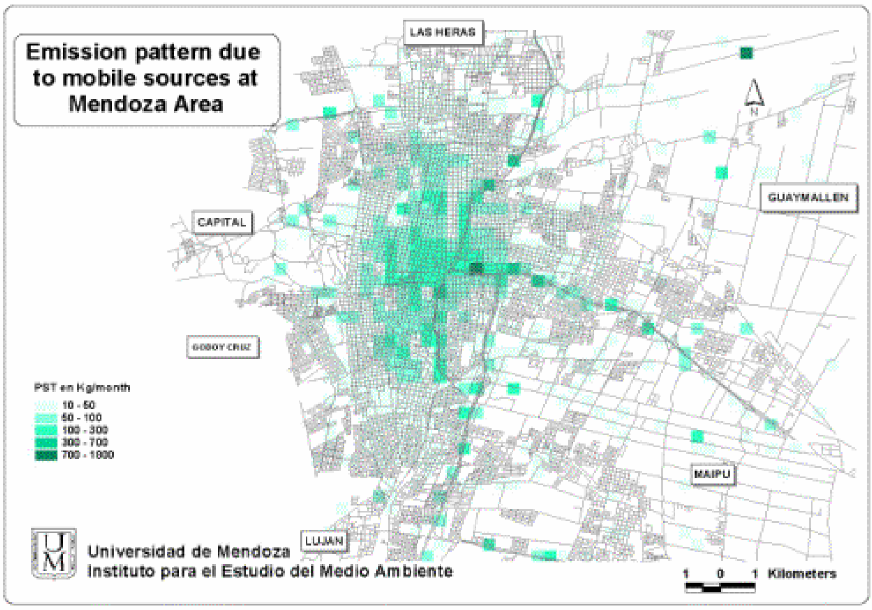


Figure 7: Emission pattern of total suspended particulate matter for mobile sources in Mendoza

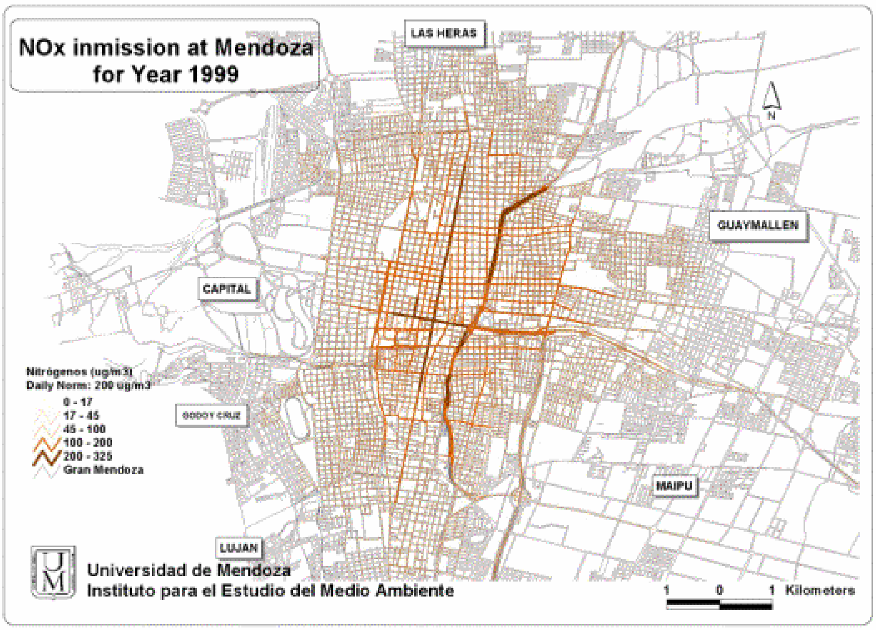


Figure 8: Ambient concentration values of NOx (μg/m^3) produced by the road vehicles in Mendoza.

The power plant at Lujan de Cuyo is the main NOx emitter, but the concentration values do not exceed the local standard (100 μg/m^3 for 1 year and 200 μg/m^3 for 24 h). Mean daily values reaches de 20 to 40 μg/m^3 and annual mean do not exceed 5 to 10 μg/m^3, due to industrial sources. NOx values at the urban areas are mainly produced by vehicle exhaust. Figure 9 shows the ambient concentration of averaged 24h of particulate matter. While figure 10 shows a daily mean concentration map of nitrogen oxides emitted from the same industrial area

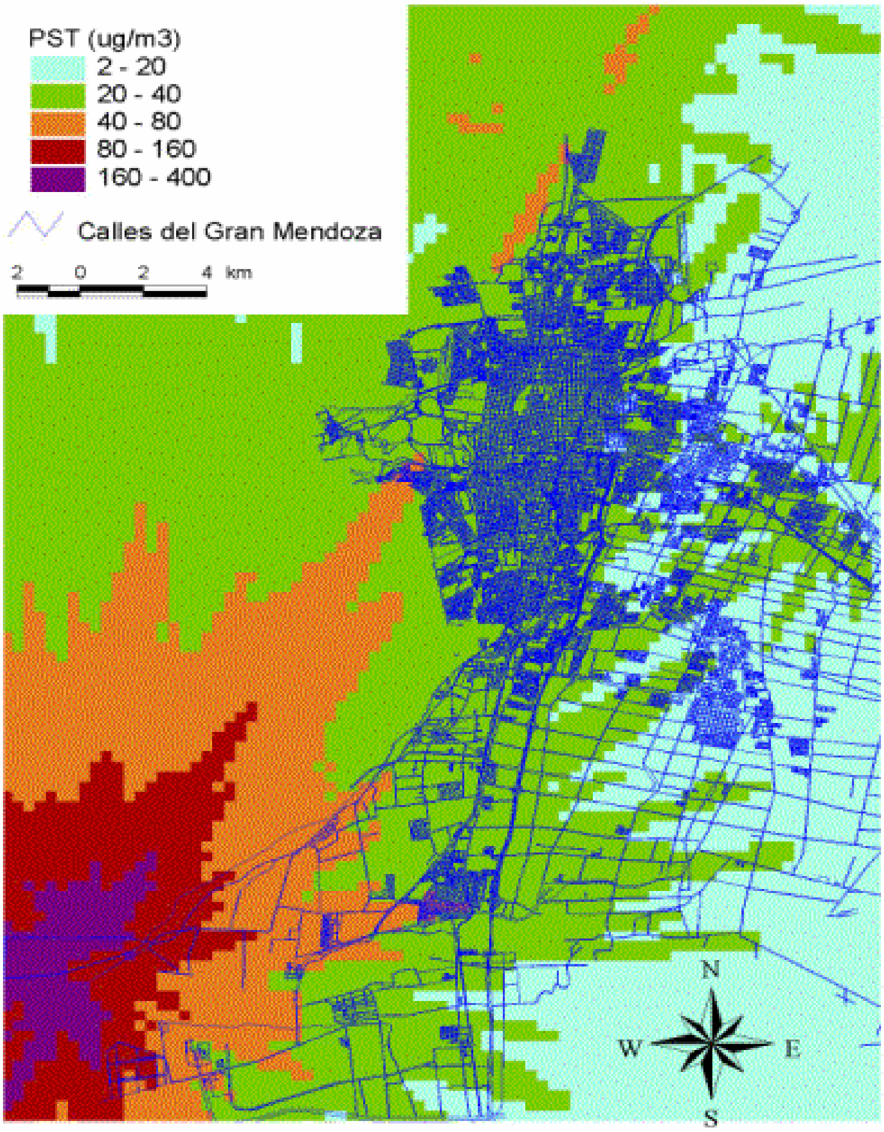


Figure 9: Average 24 h mean value of particulate matter for years 1996-1999

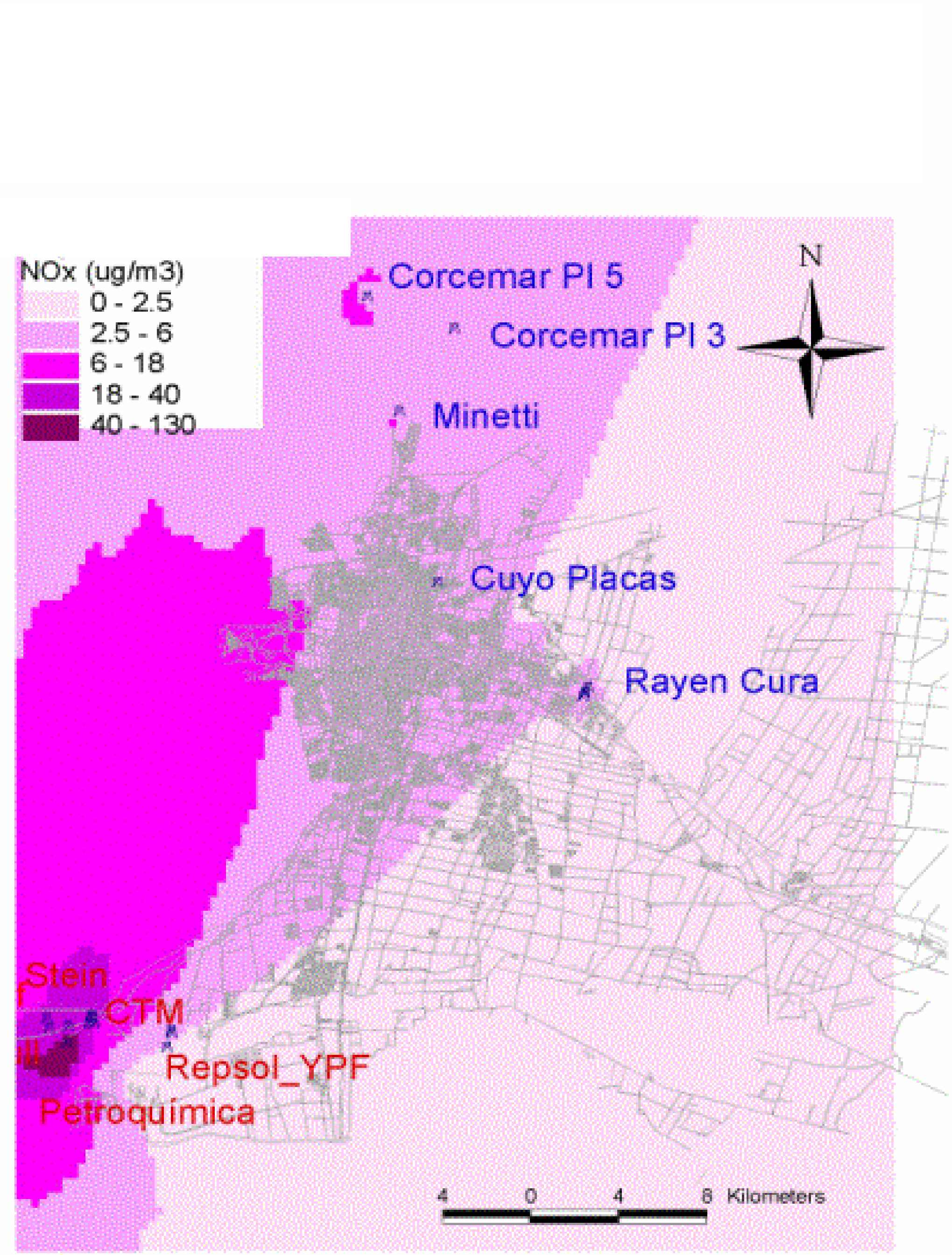


Figure 10: Annual daily mean value of nitrogen oxides for years 1996-1999

3.2 Simulation of future scenarios

Once a simulation scenario is chosen, the principal calculations are the geographical distribution of daily traffic flow, emissions and ambient values for air pollutants. Normal output for this model are: a) daily vehicle fluxes, b) daily mean emission for TSP: Total suspended particles, NOx: Nitrogen oxides, HC: hydrocarbons and CO carbon monoxide; c) total emissions for given areas of the city, discriminated according to the vehicle type and fuel; d) expected ambient concentrations for the present situation, and for example for year 2010 under several scenarios.

The total daily emissions for the city, for an approximate area of 25 x 20 km, can be calculated as a function of the type fuel consumption, which can also be interpreted in terms of private (mainly gasoline) and public (mainly diesel) transport. This information is displayed in Table 4, while Table 5 shows this data as a ratio of emission to transported passenger. These two tables clearly remark that the public transport has a better overall performance than private cars, considering total daily emissions. Only for particles (total mass) diesel buses are worst than the gasoline vehicles. As an example we will display the result of a simulation study, where it was supposed a change in transport system, by incorporating an electric tram to replace part of the diesel buses. Table 6 shows a comparison of the estimated total mean daily emission of the city, calculated for: a) year 1999; b) year 2010, no change in public transport system (SI); and c) year 2010 with a new proposed electric tram system (SII).

Table 4: Daily emission of pollutants by fuel type in kg for year 1999.

Emission (in kg) / Transport mode	Public (diesel)	Private (gasoline)
Total suspended particles (TSP)	600	400
Nitrogen (NOx)	850	2500
Hydrocarbons (HC)	950	2900
Carbon monoxide (CO)	5250	18400

Table 5: Ratio of the daily emissions to carried passengers for year 1999.

Emission per passenger (in g/pass.)	Public (diesel)	Private (gasoline)
Total suspended particles (TSP)	1.15	0.60
Nitrogen (NOx)	1.65	3.65
Hydrocarbons (HC)	1.80	4.25
Carbon monoxide (CO)	10.25	26.65

Table 6: Total daily emission of pollutants by mobile sources in tons, for two future scenarios (SI and SII).

Contaminant (in tons)	1999	2010 (SI)	2010 (SII)
Total suspended particles (TSP)	1	1.4	1.0
Nitrogen (NOx)	3.4	4.3	3.2
Hydrocarbons (HC)	3.9	4.7	2.7
Carbon monoxide (CO)	23.6	30.3	18.0

It is foreseen for year 2010 an increase in air pollutant emissions from 20 to 40%, under the scenario presented in Tables 2 and 3. Consequently a worsening of the air quality is expected, both in absolute concentrations values as well as an extension of the affected area. As an example, figure 11 (a) shows the calculated ambient concentrations of hydrocarbons for year 1999, (b) 2010 and (c) plots how the area with critical ambient concentrations values could be reduced in extension and in absolute values, when the expected tram project is carried out. A higher positive impact is expected on carbon monoxide and hydrocarbons emissions, because of their non linear dependence with the vehicle velocity. This double effect will improve or at least stabilize the present air quality in the city, despite the expected population and traffic growth. As traffic density increases, lower speeds are developed and hence producing higher emissions. On the contrary, as more users prefer a clean and safe electric public transport, traffic intensity will diminish considerably, and higher regular speeds can be achieved for those who use private transportation.

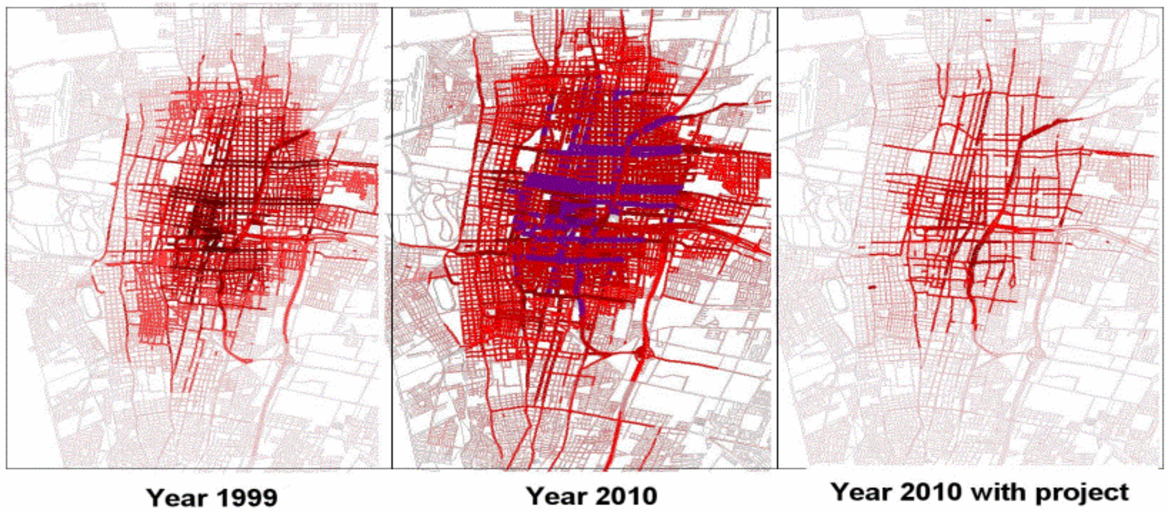


Figure 11: Calculated hydrocarbons emissions a) for year 1999, b) with present diesel public bus system for year 2010 (SI), and under the projected electric public system scenario (SII).

4 CONCLUSIONS

The city of Mendoza has implemented a vast environmental program. This program includes various technical and legal aspects such as: a) environmental information; b) legal, and economic instruments for environmental protection; c) development of public environmental awareness; d) natural flora and fauna preservation; e) environmental control and sanitation; f.) urban regulation and development; etc.

An important task of an air quality management system is to establish suitable air quality targets; and to determine how effective these targets are temporally and geographically complied. Another important aspect is to forecast the possibility to reduce pollution emissions. Such an air quality system has three important components: monitoring of main pollutants; realization of a comprehensive model, and development of satisfactory legal strategies. This article emphasizes the modeling efforts. The implemented model is based on a Geographical Information System, which offers various advantages to handle spatial and temporal data. GIS combines data with algorithms, procedures and models that represent general scientific understanding. In this article we showed the actual air quality situation in the city and we presented, as an example two possible future scenarios.

5 ACKNOWLEDGEMENTS

The authors would like to thank the authorities of the University of Mendoza for the support to the research activities. We thank as well the Ministry of Environment and Public Works of the Province of Mendoza, for permitting the use of the data from the monitoring stations. Our gratitude to the German colleagues from the Center for Environmental Research in Leipzig, represented by Prof. Dr. Olf Herbarth and Dr. Ludwig Weißflog for their friendly and fructuous cooperation. This study was partially funded by Argentine-German International Scientific Cooperation and the Argentine Agency for Science and Technology (FONCYT) under grant PICT97 N° 13-00000-01579.

6 REFERENCES

[1] Schlink, U., Puliafito, E., Herbarth, O., Puliafito, J.L., Richter, M., Puliafito, C., Quero, J., Endlicher, W., Zahnen, B. Ozone air Pollution in Mendoza. in *Air Pollution VI, Serie Advances in Air Pollution*, Brebbia C., Ratto C., Power H. (Eds.), Witt Press, pp 435-444, 1998.

[2] Schlink, U, Herbarth, O., Richter, M., Rhewagen, M., Puliafito, J.L., Puliafito, E., Puliafito, C., Guerreiro, P., Quero, J.L., Behler, J.C. Ozone-Monitoring in Mendoza, Argentina: Initial results. *J. Air and Waste Management Assoc. 49, 82-87*, 1999.

[3] Puliafito E., Puliafito, J.L., Behler J.C, Alonso, P. La calidad del aire en Mendoza: Contaminación y efectos sobre la salud. In *Mendoza Ambiental*, Martinez, E. and Dalmasso, A., (Eds.), pp. 207-242, Mendoza, Argentina. ISBN 950-43-7961-6, 1995.

[4] Weißflog, L., Paladini, E., Gantuz, M., Puliafito, J., Puliafito, S., Wenzel, K., Schüürmann, G. Immission patterns of airborne pollutants in Argentina and Germany. I. First results of a heavy metal biomonitoring. *Fresenius Environm. Bullet.* (3) 728-7233.

[5] Wenzel, K., Weißflog, L., Paladini, E., Gantuz, M., Guerreiro, P., Puliafito, C., Schüürmann G. Immission patterns of airborne pollutants in Argentina and Germany. II. Biomonitoring of organo chlorine compounds and polyciclic aromatics. *Chemosphere* 34, pp 2505-2518, 1997.

[6] Puliafito, J.L: A South American Country Example: Environmental legislation Enforcement in Mendoza; Experience and challenges. *Proc. of the Third International Conference on Environmental Enforcement*, Vol. 2, pp51-62, Oxaca México, April 25-28, Gerardu, J., Wesserman, C., USEPA and Ministry of Housing and Spatial Planning and Environment (VROM) the Nederlands; VROM8300/133, 1994.

[7] Herbarth, O., Fritz, G., Behler, J.C., Rehwagen, M., Puliafito, J.L., Richter, M, Schlink, U., Sernaglia, J., Puliafito, E., Puliafito, C., Schilde, M., Wildführ, W. Epidemiologic Risk analysis of environmentally attributed exposure on airway diseases and allergies in children. *Centr. Eur. J. Publ. Health* 7, (2), pp 72-76, 1999.

[8] Herbarth, O., Fritz, G., Wildfür, W., Behler, J.C. An epidemiological study to the effects of traffic and domestic heating attributed emissions on respiratory illness and allergies among children, *Epidemiology*, 7(4),86, 1996.

[9] Zanetti, P. *Air pollution modeling*. Computational Mechanics Publications, Southampton Boston. Van Nostrand Reinhold, New York, 1990.

[10] Seinfeld, J. *Air pollution, physical and chemical fundamentals*. McGraw-HilL, NewYork. 1975.

[11] CONCAWE Reports: Motor vehicle emission regulations fuel specifications, Part 1, summary and annual 1996 update. Reports, No. 5/97, 1997.

[12] Andrias, A., Samaras, Z., Zafiris, D., Ziercok, K. CORNAIR Working Group on emission factors for calculating 1990 emission form road traffic. Final report, *Document of the European Commission ISBN 92-826-5572-X*,1993.

[13] Hoydish, G., Dabbert, F. Kinematics and dispersion characteristics of flows in asymmetric street canyons. *Atmospheric Environment*, 22, 2677-2689,1988.

[14] Puliafito, E., Guevara M., Puliafito, C.: "Characterization of urban air quality using GIS as a management system", *Environmental Pollution*, 122, 105-107, (2003).