Modelling air pollution in an industrial area using GIS as an assessment tool

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Abstract

To assess the air pollution impact to the city of Mendoza, from a nearby industrial park, a model was developed based on a Geographical Information System (GIS). This system is used to evaluate the emission-immission patterns due to its ability to handle spatial data, source inventories, measurements and meteorology data. To evaluate the industrial park environmental data was gathered from a) continuous monitoring of NO\(_x\), O\(_3\), CO and total particles (TSP) at different sites in the area, b) several, fixed stations of 24 h measurements of NO\(_x\), SO\(_2\), TSP and Pb, c) samples of particulate matter using a high volume pump at several measuring points, d) local meteorology and e) an emission inventory of the industrial park. The results of the model for different conditions will be presented for the main contaminants.

Emission from vehicles where also considered in the urban area which permits a comparative evaluation of the impact of fixed sources to mobile sources.

1 Introduction

Particulate and gaseous emission of pollutant from industries and auto-exhaust are responsible for rising discomfort, increasing airway diseases, decreasing productivity as well as for the deterioration of artistic and cultural patrimony in urban centers. In the central metropolitan area more than 70% of the emission of main contaminants comes from mobile sources. The main industrial areas are
located on the periphery of the city, contributing to the other 30%. The metropolitan area of Mendoza, reaches an extension of about 40 x 50 square km. From the air quality point of view it is easy to locate three main industrial areas: a) an oil refinery, a petrochemical industry and a gas power plant; situated SW of the city b) two cement industries and other minor sources on the north edge and c) the agro and food production mostly located on the east side of Mendoza, but with a minor impact on the air resource.

2 Main objective

The main objective of this project is to develop a planning tool to help local authorities and interested users to evaluate the present air quality or to assess on the environmental impact of future scenarios, localization of new industries, changing urbanization conditions or transportation systems and increasing vehicle circulation. Particularly this study aimed to establish the air quality in the southern industrial area of the city of Mendoza and its influence in the urban area.

3 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 5000 m with peaks up to 7,000 m. This natural barrier influences the meteorological conditions determining a strong dependence in the air pollution situation. The city is located in an arid to semi-arid zone of low rainfall: 120 to 400 mm/a, mean 230 mm/a, which occurs specially during the summer months (November to March). The annual mean wind intensity is 2.6 m/s, with 19 % of calm days, the predominant wind directions are: S-SW, 30%, E-SE, 24%, N-NE: 14%, W-NW, 8%. Due to its closeness to the mountains, Zonda winds similar to Föhn or Chinook winds prevail in the higher layers most of the year. This is a warm and dry NW wind with speeds ranging 5-6 m/s, and gust up to 12 m/s. Zonda winds and anticyclone situations in the winter months (May to October) with high probability of frost, contributes to a higher degree of pollution due to the occurrence of strong thermal inversion layers. The area presents low relative humidity (50%), low incidences of fog and few days with covered skies (65-75 days/annum). An important feature for the description of the air pollution is the day-night variation, characterized by a typical valley-mountain circulation. From 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, varying between 100-200 m at night to more than 2000 m at midday, depending on the day of the year. More on climatology and meteorology of the region are described in Schlink [1] and Endlicher [2].

4 Monitoring and sampling

In the urban area of Mendoza, the Ministry of Environment monitors since 1970 (in some stations) and since 1990 in around 20 sites: 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 SO2 -by colorimetric West and Gacke modified by Pate-. Also, our Institute for Environmental Research (IEMA), measures since 1995, in cooperation with the Center for Environmental Research (UFZ) in Leipzig, Germany, black carbon and PAH poliaromatic compounds (Aethalometer GIV reflectometry), surface ozone (O3), nitrogen oxides (NOx), carbon monoxide (CO), using a set of Horiba instruments (series APO350E for O3 and APN360 for NOx and CO) and meteorological parameters, including solar global radiation. Principal results of the monitoring measurements have been reported in [1,3,4] and related epidemiological studies in Herbarth [5]. Additionally, in the frame of this cooperation, immision pattern of heavy metals have been analyzed using samples of pine needles, taken at different sites (Weißflog [6], Wenzel [7]).

For the present study, also samples of particulate matter have been taken using a high volume pump at several measuring points. The filter papers were analyzed at the DETI Laboratory from the National University of Cuyo, Mendoza.

5 Methodology

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. We distributed two forms among the industries, small factories, gasoline stations, and so on, asking for relevant information on type of fuel, yearly consumption, physical data of boilers, chimneys and emission measurements if available. For this study, we used not only the information gathered from the enterprises, but also emission measurements performed by independent consultants. These measurements were taken using an isokinetic stack samplers, following U.S. EPA Standard Methods.

We use the Gaussian multi source dispersion program ISCT3 from EPA to simulate the air quality due to the presence of the industrial sources. For these
calculations we have used several years of meteorological data measured at our Institute and from the National Weather Service collected at the airport. These calculations represent adequately daily, monthly and annually mean values, and are suitable for compliance with the air quality standards. Therefore, the aim is to characterize areas with potential increase in air pollution, and less to establish exact immission values. To calibrate the results of the models, we used data from different monitoring stations and sampling methods for the principal contaminants.

The geographical location of industrial sources were positioned using a GPS receiver. As a receptor grid, the city of Mendoza was divided in square of 350 x 350 m. For specific areas, the model includes a smaller grid of 100 x 100 m. The results of the calculated and measured immission form both mobile and fixed sources are represented on the receptor grid through a Geographical Information System (GIS).

Mobile sources are characterized by using emission factors for different fuel and vehicle types, average driving distances, traffic counting in main streets, structure of the automotive park and public surveys [8].

6 Calibration of the model

To calibrate the models and to understand the local meteorological and emission situation, we used the data from the monitoring stations and from the particular measuring campaigns in the industrial area. One of these campaigns were performed during end of September through December 2000, where samples and monitoring of main pollutants where gathered in the industrial complex situated at the SW of the city. There, we identify five main stationary sources: an oil refinery and a petrochemical industry as main emitters of particles and SO2; an energy power plant, mainly based on natural gas, with important NOx emissions; and two medium companies responsible for black smoke fumes, one producing metal and ferrous alloy, and the other producing coal briquettes for heating. Each of these two industries have also open piles for the storage of iron and coal respectively, which were included as area sources. Figure 1 shows a time series of black carbon, taken at the site close to the power plant, between Sep. 25 and Oct. 30. These data were compared with a gravimetric method, by taking several samples on a paper filter (48 hours each) using a high vacuum pump. The measured data show a near Poisson distribution, with mean values of 68 μg/m³, a median of 37 μg/m³, with a 98 percentile of 330 μg/m³. More than 20 % of hourly mean values exceeds 70μg/m³. Analyzing the location of the stationary sources and the wind direction with respect to the measuring site, we observe that the SW-NE is the predominant wind direction according to the valley-mountain circulation mentioned above. During the morning hours, the soft ENE wind blows taking the main pollution from the industrial area to the mountains, leading to lower immission values. At night the circulation switches blowing from WSW producing the maximum measuring values. From the 25 days measured at the
site, there were 3 periods of 24 hours where the maximum daily NOx values (200 µg/m³) was exceeded. From 950 measurement hours, 90% of the time ozone was slightly over the maximum hourly standard value (63 ppb) with similar values for all wind directions. While the hourly CO measurements were always below the air quality standard (36 ppm -1 hour).

Our next step was to simulate the immission values at the monitoring sites using the measured meteorological conditions. Figure 2 shows the calculated immission for particulate matter as function of the wind direction, and hour of a day compared to the measured values. A correlation coefficient of $R=0.94$ ($R^2=0.89$) was obtained for 25 days average hourly mean values. This figure represents the degree of correspondence obtained in the simulation of the industrial area. Some differences still persists, probably by not including all minor sources of the industrial park and effects due to the closeness of some sources.

![Figure 2: Calculated immission for particulate matter as function of the wind direction, and hour of a day compared to the measured values.](image)

**Figure 1:** (a) Measurements of black carbon at the industrial park and (b) its frequency distribution for hourly mean values.
7 Results

Once a good fit was obtained for the different monitoring sites, the immission situation was estimated for the entire city of Mendoza. Two years (1997-98) of meteorological data were processed, including 1320 hours (where 400 hours represent almost calm conditions). Four different conditions were calculated, maximum hourly values, 24 h, 30 days, and annual mean values. We will briefly describe below, the main results for each principal pollutant.

Figure 2: Measured and simulated mean values of black carbon with respect to (a) wind direction and (b) hour of a day.
Particulate matter: 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 µg/m³ and more than 200 µg/m³ daily mean values close to the sources. Ten kilometers away, at a residential part of the city annual mean values of 30 to 40 µg/m³ can be obtained, especially during the winter months. According to our calculations and the monitoring measurements, the influence of the industrial sources over the city, do not exceed the air quality standard with the exception of areas close to the industrial area. Figure 3 shows a monthly mean value in the southern industrial area.

Sulphur dioxide: The main source of SO₂ is the refinery, reaching maximum hourly values at the urban areas of the city of 100 µg/m³, and more than 400 µg/m³ in Luján. Most of it is vented through the torch. Lately the refinery has incorporated a desulphuration Claus plant to reduce their SO₂ emissions. The city has maximum 8-hour values of 100 to 200 µg/m³, and mean annual values of 20 to 40 µg/m³, depending on their relative location. According to the local air quality standard, only some areas close to the refinery exceed the norms.

Nitrogen oxides: The power plant at Luján de Cuyo is the main NOₓ emitter, but the immissions values do not exceed the local standard (100 µg/m³ for 1 year and 200 µg/m³ for 24 h). Mean daily values reaches de 20 to 40 µg/m³ and annual mean do not exceed 5 to 10 µg/m³, due to industrial sources. NOₓ values at the urban areas are mainly produced by vehicle exhaust.

8 Conclusions

The developed model handles relevant data to establish an emission inventory including both stationary and mobile sources. This information system integrates in a friendly way source information, meteorological data, monitoring measurements, and offers a tool for calculation of the immission patterns for several contaminants, such as particle, NOₓ, CO and HC.

With respect to the compliance to the local standard of air quality, only some areas in downtown have several days per year where daily standard are exceeded, especially in total suspended particles and NOₓ with high hourly values, specially due to mobile sources. But calculations on future scenarios based on population growth, increasing vehicle circulation, (including an improvement in vehicle technology), shows a widening of the affected area and an increase in pollutant emission around 25% increase in the next 10 years [8].

In the northern and southern edge of the city the air quality standard are exceeded due to stationary sources principally for total suspended particles and ozone, and occasionally NOₓ and SO₂, if the proper abatement process are not well fitted.
Finally, it is foreseen to set a public Internet access to the model which can be consulted by environmental engineers, urban planners or city officials to evaluate present air quality or to assess on future scenarios such as modifying public transportation system, or installation of new stationary sources.

**Figure 3:** Model output for maximum monthly values of TSP for the industrial area.
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10 References


