Emission Inventory in Medellín (Colombia) city.
An Approximation

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Abstract

An atmospheric emission inventory has been processed in the Aburrá Valley were Medellín. The purpose of the study is to consider the annual emission of air pollutants. This is necessary to be applied to the project named PAMOMED (Photochemical Air Modelling in Medellín) undertaken by UPC, UPB, and AUTH. The domain of the study covers an area of 40 x 40 km² (1600 km²) with a time resolution of one hour and spatial resolution of 1 x 1 km². The emission of the pollutants have been defined in each cell and they are usually expressed as amount of mass per surface unit in a period of 24 hours.

The inventory includes the main emitting sources such as mobile, biogenic and industrial sources. The Air pollutants are SO₂, TSP, NOx, CO and VOC. This last one is specified in the main group of hydrocarbons.

Key Words: Air pollution, biogenic emissions, emission factors, emission inventory, emission sources, industrial emission, traffic emissions.

1. Introduction

Medellín city is located in the Aburrá valley, which is one of the most important populated and industrial areas in Colombia. However, up to date there was not carried out any systematic study to build up an atmospheric emission inventory in this area. The purpose of this study is to estimate the annual emission of air pollutants from the main sources in the Aburrá valley. This task is the first stage in the project named PAMOMED (Photochemical Air Modeling in Medellín) that is being undertaken by UPC, UPB, and AUTH.

Aburrá Valley is located in the northwest of Colombia between 5° 25’ and 8° 55’ latitude west and between 73° 53’ and 77° 07’ longitude north. It is at 1500 meters above the sea level (m asl) and the annual average of temperature is 20°C.

The valley area is 1152 km²; the land use is distributed as: urban 16%, forest 14%, farmland 30%, scrub woodland 15%, and others 25%. The city is communicated with the surroundings regions by five main roads, although has two airports: one located inside the valley and other at 40 km in Rionegro city at the east of the valley.

The domain of the study covers an area of 40 x 40 km² (1600 km²) with a time resolution of one hour and spatial resolution of 1 x 1 km². The highest altitude is 6000

m asl which is divided in 35 variable-width layers. The emission of the pollutants have been defined in each cell and they are usually expressed as amount of mass per surface unit in a period of 24 hours. In the figure 1 is shown the domain of the inventory.

![Figure 1 Domain of the inventory](image)

Figure 1 Domain of the inventory. Representation of the Aburrá valley in the center of the domain.

The inventory includes the main emitting sources such as mobile, biogenic and industrial sources. The air pollutants considered are: \( \text{SO}_2 \), TSP, \( \text{NO}_x \), CO and VOC. This last one is assumed to be composed by a profile of the main organic compound families (pseudo-compounds): alkanes, alkenes, aromatics and aldehydes. The emissions from industries and vegetation were estimated by applying the emission factors obtained by the Environmental Protection Agency (EPA, 2000). The emission factors of the CORINAIR study (Corine, 2000) (Veldt et al., 1988) were used for the estimation of mobile sources.

2. Methodology for estimation of the emissions

In order to assess the contribution of the metropolitan area of Aburrá Valley to the biogenic emission of photochemical precursors of ozone gases, we analyzed the land use data for the vegetation which was classified as: forests (conifers and eucalyptus), scrub woodland and farmland (potato, bean, corn and coffee). We applied the model G93 (Guenther et al., 1993) using the emission factors obtained from the BEIS program developed by EPA.

For the industrial emissions, the emission factors of the combustion, chemical and food processes were considered. In Medellin half of the processes consists of steam or energy production, whereas the remainder are chemical, metallurgical and food ones. Most of the factories use fuel oil no. 2, fuel oil no. 6 and coal for the combustion processes. We
have applied the EPA emission factors for the main pollutants, and the CORINAIR emission factors for the split of VOC such is shown in table 1 (Costa, 1995).

Table 1 VOC profile (Veldt et al., 1988).

<table>
<thead>
<tr>
<th>POLLUTANT</th>
<th>COAL</th>
<th>FUEL OIL</th>
<th>GLP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>75</td>
<td>20</td>
<td>75</td>
</tr>
<tr>
<td>Alkanes</td>
<td>9</td>
<td>55</td>
<td>12</td>
</tr>
<tr>
<td>Alkenes</td>
<td>6</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Aromatics</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Aldehydes</td>
<td>5</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

For the road traffic emissions, the study area was divided in 1-km² cells that enclosed the main avenues in the city and roads. Starting from the information of vehicular capacity of the years 1997 to 2000, as well as the adopted emission factors of the CORINAIR European methodology, a procedure was elaborated based on balances of vehicular flow and a computer program to calculate the hot emissions to the atmosphere. As a result of the simulation, it was possible to determine the hourly emission of each one of the pollutants in the respective cells for a typical labor day.

3. Results

The results obtained from the estimations of the emissions of the sources are shown in table 2 and figures 2, 3, 4 and 5. The greatest contribution of TSP and SO2 is due to the high consumption of coal by the industries. The highest concentrations of NOx are produced by the industries and road traffic and in a low percentage by the vegetation.

Table 2 Total emissions in Medellín city

<table>
<thead>
<tr>
<th>EMISSION T/YEAR</th>
<th>TSP</th>
<th>SO₂</th>
<th>CO</th>
<th>NOₓ</th>
<th>VOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industries</td>
<td>29261</td>
<td>11392</td>
<td>900</td>
<td>5707</td>
<td>43</td>
</tr>
<tr>
<td>Road traffic</td>
<td>492</td>
<td>472</td>
<td>52446</td>
<td>8031</td>
<td>12436</td>
</tr>
<tr>
<td>Biogenic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>342</td>
<td>6000</td>
</tr>
<tr>
<td>Total</td>
<td>29753</td>
<td>11864</td>
<td>53346</td>
<td>14079</td>
<td>18479</td>
</tr>
<tr>
<td>%</td>
<td>23</td>
<td>10</td>
<td>42</td>
<td>11</td>
<td>14</td>
</tr>
</tbody>
</table>
CO is the most emitted pollutant in Medellín. CO emissions are basically due to the vehicles and are caused by the deficient combustion of fuel in the rush hours when there are the greatest traffic jams, as can be observed in figure 6. The traffic pattern shows that the highest amount of cars appears between 7:00 and 8:00 h in the morning and between 18:00 and 20:00 h in the late afternoon.
Figure 6 Percentage of vehicle flow vs. Hour. Variation of the traffic hour by hour in a labour day

In general, Medellin’s downtown represents the most affected area by the sources, followed by the center-western region as can be seen in figures 7 to 10. Likewise, for the analyzed area, the biggest emissions were evidenced in the hours of the day, with marked picks at 8:00 h in the morning and 19:00 h at night.
Figure 7 Distribution of VOC emissions (kg/h) in the study area: The emissions of VOC are distributed by all the domain in a range of 0.001 to 150 kg/h. The highest emissions are located in the valley. In the rural areas the highest emissions reach 10 kg/h.
Figure 8 Distribution of CO (kg/h) emissions in the study area: The highest values of CO emissions are in the center and in the south of the valley where road traffic and industrial activities are concentrated.
Similar to the VOC emission patterns, the highest emissions of NOx are in a range of 1 to 100, while in the rural areas are lower.
Figure 10 Distribution of TSP (kg/h) emissions in the study area. The highest values are concentrate in the center of the valley with a emission range between 10 to 200 kg/h. This place is the most populated area in the valley.
The variation of the emissions during a common day is shown in figure 11. We observe that the traffic emissions are bigger than the biogenic ones. At the same time, the highest biogenic emissions occur at 13:00 hours, and increases during the day by the effect of the solar radiation and the ambient temperature.

**Figure 11 Variation of the emissions during a common day.** Traffic emission are higher than biogenic emissions.

The population of Medellín is 2.9 million inhabitants. The density of population is 14400 inhabitants/km², this means that in some places in the valley where is located the industrial activities are many people affected by the emissions.

The quantity of pollutant generated by people per year is near to 121180 tons. Comparing this values with the Barcelona inventory we see that in this city the population is 3.6 millions inhabitants and the annual anthropogenic emissions are 236620 tons. The density per each city is:

Medellín 0.0417 tons/people/year
Barcelona 0.0657 tons/people/year.

In Barcelona the density is higher than in Medellín probably for the differences in the fuel and in the amount of the sources evaluated.

### 4. Conclusions

Medellín’s downtown is the most affected area, followed by the center-western region. The total amount of pollutants emitted in the area is about 127000 tons per year. Among the sources considered, Road traffic is responsible for 58% of the total emissions; Industries 37%; and Biogenics 5%.
The highest emissions from road traffic occur between 7:00 and 8:00 h in the morning and between 18:00 and 20:00 h in the late afternoon, in accordance with the rush hours.

CO is the most emitted pollutant: 70% of the road traffic emissions.

The greatest contribution of TSP and SO2 is due to the high consumption of coal by the industries.

The highest concentrations of NOx are produced by the industries and road traffic and in a low percentage by the vegetation.

The difference between the Barcelona and Medellín’s inventories could be that in Medellín city just was calculated the 3 most important sources. Therefore could be interesting to evaluate the emission from additional sources such as aircraft, gas stations etc. Too is important reevaluate the emission factors for the vegetation, because of is a tropical region far different from the temperate regions in which the EPA factors are referred.

This study has allowed us to obtain a first approach of the emission level of photochemical precursors that are emitted in Medellín by using emission factors obtained elsewhere. These results will be applied in a photochemical model in order to know the most affected areas from the air quality point of view, to take the necessary actions for controlling and reducing the emissions. In the future we hope to make studies about the emission factors focused in the tropical vegetation in order to obtain a more accurate contribution of the natural sources.

5. Acknowledgments

Thanks for the economical support to: Instituto Colombaino para el Desarrollo de la Ciencia y la Tecnología “Francisco Jose de Caldas” COLCIENCIAS and Area Metropolitana del Valle de Aburrá.

6. References


Modelo BEIS EPA Documento EPA/600/R-99/030<www.epa.gov/chief.html, 2000>