AIR POLLUTION MANAGEMENT IN GROWING URBAN AREAS

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ABSTRACT

In growing urban areas, mainly in large cities, the results achieved in terms of air quality in the last couple of decades do not seem consistent with the accomplished high reduction of emissions, at least for some pollutants.

This means that some important aspects have been missed or underestimated, related to growth of population, expanding urban areas, mobility demand, increasing energy consumption or whatever.

The current trend is to work on mobility and urban planning through measures (access restriction areas, circulation banned to non-catalytic cars, circulation allowed to alternate plate numbers, non-driving day, etc) which often do not lead to an effective improvement in air quality.

Through a Gaussian model for area sources, the weight of some variables (emission density, urban area size, population density, meteorology), which are mainly responsible of air quality, is evaluated rather than the actual concentrations. Indeed the lasts are scarcely predictable without a reliable emission inventory which, on its turn, is a very difficult and insidious task.

The same mathematical approach has been used to gain some considerations on the efficacy of the measures which are currently taken to tackle air pollution and on the future scenario coming from possible growth factors of some mentioned variables.

INTRODUCTION

In the last couple of decades great efforts has been done, especially in industrialised countries, in order to reduce air pollutant emissions which actually show a general decreasing trend. However, in urban areas and megacities where large part of the population lives (in Europe some 80% of the citizens), the results achieved in terms of emission reduction did not produce equal surface concentration reduction, that is they were not sufficient to compensate the growth of population, transport, energy, general consumptions, mobility demand, urban area. Therefore the air quality targets and limit values, in particular for ozone, PM_{10} and NO_2, are currently exceeded in many urban area and in particular in megacities not only European and the situation in the future could be even worst since more severe targets have to be met within 2010 [1,2,3].

To tackle air pollution the current trend is to work on mobility and urban planning through measures (access restriction areas, circulation banned to non-catalytic cars, circulation allowed to alternate plate numbers, non-driving day programs) which often seem not able to lead to an effective improvement in air quality, while some variables more directly responsible for air quality (emission density, expanding urban area, meteorology) are not taken in due account in air pollution management.

On the other side complex mathematical models, extensively developed and used in recent years, may produce results congruent with locally monitored data, given that a reliable stationary emission source inventory is available together with traffic count and vehicle fleet composition data, all of which are very scarcely predictable.

Here the problem has been approached through a simple mathematical model just to draw general considerations on the efficacy of the main measures which are currently taken and on future backgrounds coming from possible growth of the mentioned variables.

THE MATHEMATICAL MODEL

A simple mathematical model has been used derived from the general Gaussian diffusion equation for point sources. It has been firstly modified for line sources and then extended to area sources, assumed as composed by numerous closely packed rows [4].

The equation takes the form:

$$C = \int_{r}^{r_2} q_a(r) \frac{2}{\sqrt{2\pi} u \sigma_z} dr \tag{1}$$

where C is the concentration at a specific receptor point, r_1 and r_2 are the distances from the extreme boundaries of the upwind portion of the urban area to the receptor site for each wind direction, q_a *(r)* is the local emission density within the urban area, u is the wind speed, σ_z is the standard deviation of the distribution of pollutant concentration in the vertical direction.

To simplify the calculations it has been assumed that the urban area has a circular form with a radius R and that the emission density has a symmetrical distribution, with respect to the centre of the city, which may vary from a classical Gaussian shape to a uniform value all over the city. In order to include all the possible configurations eq. 1 has been modified with an exponential term:

$$C = \int_{r}^{r_2} q_a \frac{2}{\sqrt{2\pi} u \sigma_z} e^{-\frac{s^2}{2\sigma_p{}^2}} dr \tag{2}$$

where q_a is the maximum emission density in the centre of the city, s is the distance of a generic point of the city from its centre, while σ_p is a standard deviation which characterizes the emission density distribution within the urban area. In this way $\sigma_p >> R$ simulates a nearly constant emission density all over the city, while, for example, $\sigma_p = R/3$ means that the emission sources decrease in a Gaussian shape from the centre toward the outskirts of the city. The background concentration immediately outside the city has been assumed to be not influent.

Here the model has been used to compare different situations rather then to calculate reliable values of concentration, so that q_a=1 has been always used. For the dispersion parameters the estimations suggested by Briggs for urban area have been adopted [5] with a constant, in the initial growth phase within 100 m, equal to $\sigma_z(50)$ to simulate a kind of initial buoyancy induced dispersion. Of course this is an approximation which does not influence comparative evaluations, but has to be reviewed when the aim is to draw from the model reliable concentration values.

For each geographical area it is assumed to know the meteorological characterisation in terms of frequency of the wind blowing in 16 directions associated to 6 Pasquill stability categories and 5 wind speeds. The calm wind situations here have been considered within the first wind speed class (0 to 4 knots). This means that in theory any place may be characterised by the frequency of 480 (16x6x5) different meteorological situations, but actually some of them have not physical meaning so practically one may have nearly 300 different meteorological configurations.

Air quality standards for several pollutants are normally defined with both a long-term (i.e. annual) limit and a short-term limit, a percentile which has not to be exceeded more then a given amount of time per year.
Calculating in each receptor point the concentrations corresponding to the known meteorological configurations and weighting the results on their frequency one may derive a statistical concentration distribution and the arithmetic mean. Then, plotting it on log-probability graph paper one may derive median and percentiles.

THE GROWING URBAN AREA

In a growing urban area, parameters are usually taken into account, in order to evaluate driving forces of air pollution emissions developing, as energy and fuels consumption, population and production growth. However it seems not unrealistic to assume that any new extension of an urban area carries with the growth of the mentioned driving forces (unless the new urbanisation is only for a specific purpose as residential or industrial or commercial area.
As a first application a city with different growing dimensions has been simulated in two different geographical area characterised by well known meteorological conditions, and in both the cases the concentration distribution in the centre of the city has been calculated. In any case it produces a quite straight line in a log-probability paper which, for the special scale used, corresponds to a lognormal distribution.
Fig.1 shows examples of concentration distributions in the centre of the city corresponding to different urban area radius (R) and for two different emission distributions, constant all along the city the first, with a Gaussian shape the second, such that $\sigma_p = R/3$. Within each family of lines the concentration in the centre of the city depends on the radius through a 1/3 power law

$$C' = \alpha R^{1/3} \tag{3}$$

where the coefficient α depends on the density distribution and on meteorological conditions.
This means that when the radius of the city double, leaving unchanged the emission density distribution, the concentration in the centre of the city increases of about 26%.
In a point of the city, different from the centre, the meteorological conditions become very influent as much as the site is far from the centre itself. In fact, the outskirts may be downwind to wider emission sources but only for shorter part of the year. The concentration distribution is no more lognormal and in the mentioned log-probability graph paper it goes down more sharply. In terms of air quality standards in the centre of the city the long-term limit (median or arithmetic mean) could not be respected, while it is easily respected on the outskirts since for a large part of the time it is upwind to the emission sources. On the other side the short-term concentrations could be high on the outskirts and the corresponding air quality standard not fully respected there. This appears clear when the emission density is constant all over the entire urban areas, while the same circumstances may happens somewhere in between the centre and the outskirts when the emission density distribution has a Gaussian shape. In real cases, where the emission sources are not uniformly distributed it may be possible that the short-term limits are not complied with just in those places of the city which are in a critical situation with respect to particular wind directions and upwind emission source distribution.

MEASURES TO TACKLE AIR POLLUTION

The main measures to tackle air pollution aim at reducing the emission density. For example, great efforts are made to achieve a better mobility, which could contribute to effectively reduce q_a but also to encourage the use of private cars?

In order to evaluate the efficacy of the access restriction areas, normally in the centre of the city, some situations have been simulated assuming a flat emission distribution all over the urban area. For example, with a radius of the access restricted area equal to 1/10 of the radius of the city and a 30% reduction of the emission density only in that area, the concentration in the centre reduces of about 14.5%. Doubling the radius of the access restricted area to 1/5 the reduction moves to nearly 17%. Stronger reduction, up to 22,5 %, is achieved with higher reduction of emission density (50%) and a smaller restriction area (1/10).
Circulation allowed to alternate plate numbers or non-driving day have always a character of emergency measures and may not be solutions for chronic polluted situations.

CONCLUSIONS

Several measures generally taken to tackle air pollution in urban areas, in particular in megacities, sometimes seem not tailored to the local situation and in any case give poor results in improving air quality and do not help too much in complying with limits and targets enforced at the European level.
In the effort to understand the efficacy of some main measures a simple mathematical model has been adopted to simulate different backgrounds of a city, assumed of a circular form, with a symmetrical emission density distribution with respect to the centre.
The following general considerations may be drawn:

- the concentration distribution which may be recorded in the centre of the city during one year follows a nearly lognormal distribution; the concentration increases with the radius of the city with a 1/3 power law, being constant the emission density distribution; the growing extension of the urban area seems a good representative driving force of air pollution developing more than growth factors of energy or fuels consumption, population, production, emission density in the urban area. Since the centre of the city is downwind to emission sources for any wind directions, it is the first place where to check for the worst annual mean concentration;
- moving to points of the city far from the centre the concentration distribution is no more lognormal, the annual arithmetic mean decreases while the maximum concentration may increase due to a critical position downwind to emission sources for particular meteorological situations; in some points it may happen that the short-term air quality limit (percentile which must not be exceeded for more than fixed amount of time per year) is not fulfil;
- access restricted areas in the centre of the city may contribute significantly to improve air quality as far as the emission density within this area is significantly reduced and/or the dimension of that area increase; actually if the area is enlarged for more than let say 1/10 of the radius of the city the reduction of concentration in the centre become more and more irrelevant; much more important is to reduce the emission density within that area to at least 50%;
- measures aimed at reducing pollutant emissions working on the improvement of the mobility may improve air quality if they do not encourage the use of cars;
- circulation allowed to alternate plate numbers or non-driving day programs have always a character of emergency measures and may not be good solutions for chronic polluted situations.

These short preliminary recommendations for air pollution management in urban areas and megacities, even if derived through a simple mathematical model which may be reviewed or adjusted to local situations, are still useful in that they give hints to direct the best measures in tackling air pollution and comply with air quality standards.

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