Evaluating conflict zones of air pollution in a mid-sized city

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Abstract

The urban argument currently assumes an extreme level of relevance for governments and the society in general, due to the exponential increase of people living in cities and the consequent associated degradation of quality of life. Growth is continuously applying pressures over resources, infrastructures and facilities, affecting negatively the standard of living in cities. In this context, evaluating and monitoring the urban environmental quality has become a main issue, particularly important when considered as a decision-support tool that contributes to more liveable and sustainable cities. Viana do Castelo is a mid-sized city located on the northwest seaside, which undertook the challenge of developing an environmental program leading to the integration in a Healthy Cities European Network. The identification of urban air quality levels and people exposure was considered a priority in this program. The scientific toolbox adopted to develop the studies includes air quality simulation models and a GIS platform. Based on traffic and site physical characteristics, air pollution maps were created and overlaid together with the land-use and population distribution layers. This combination was the basis for the identification of critical zones, both in terms of air quality levels and people exposure to this kind of pollution. Furthermore, the results were used to sort out mitigation measures and priorities, particularly important in a context of limited resources. This paper aims to present the approach, including the theoretical framework, and to discuss the results and their role within the city's quality of life argument.
Keywords: urban air pollution, air pollution modelling.

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1 Introduction

The Project Healthy Cities is, today, a worldwide movement, having on its basis the concept Health for All (HFA) in the year 2000 of the World Organization of Health and the strategies of the Letter of Ottawa which searched a way of testing the application of these principles in a local level.

In 1986 the World Health Organization (WHO) selected eleven cities in order to demonstrate that the new approaches in public health defended by HFA worked in practice. This is how the concept Healthy Cities was born.

Viana do Castelo is a mid-sized city located on the northwest Portuguese seaside, which undertook the challenge of developing an environmental program leading to the integration in a Healthy Cities European Network. Within this program, the identification of urban air pollution levels and people exposure was considered a priority.

In line with most of the EU countries, Portuguese specific legislation requires local government authorities to manage air quality in their areas, with the aim of achieving the objectives laid out in table 1.

Table 1: Portuguese annual limit values for the protection of human health [1,2].

Pollutant	Averaging period	Value
Nitrogen dioxide (NO_2)	Calendar year	40 $\mu g/m^3$
Particulate matter (PM_{10})	Calendar year	40 $\mu g/m^3$
Ozone (O_3)	8 hours (rolling average)	110 $\mu g/m^3$
Benzene (C_6H_6)	Calendar year	5 $\mu g/m^3$

The objective of this paper is to evaluate critical air pollution disturbance zones in a mid-sized Portuguese city – Viana do Castelo. The scientific toolbox adopted to develop the studies includes an air pollutants dispersion model and a GIS platform.

Based on traffic data and site physical characteristics, air pollution maps were created and overlaid together with the Portuguese limits values and population distribution layers. This combination was the basis for the identification of air quality levels and people exposure to this kind of pollution.

2 Urban air pollution

Urban air pollution became one of the main factors of degradation of the quality of life in cities. This problem tends to worsen due to the unbalanced development of urban spaces and the significant increase of mobility and road traffic. As a consequence, the total emissions from road traffic have risen significantly, assuming the main responsibility for the disregard of air quality standard [3].

The atmospheric pollutants are emitted from existent sources and, subsequently, transported, dispersed and several times transported in the atmosphere reaching several receivers through wet deposition (through rainout and washout of the rain and snow) or dry deposition (through the adsorption of particles). In urban environment the typical anthropogenic sources are mainly the road traffic and, when existing, the industrial activity.

The compounds from the exhaustion gases of the road vehicles released to the atmosphere create impacts in a different geographical scales and time [4]. Certain compounds possess an immediate and located effect. For instance, a plume of black smoke is instantly unpleasant for people observing it, while at a longtime scale repeated exhibitions to the black smoke of the exhaustion of vehicles can cause, through deposition of particles on the surface of the buildings, the darkening of their facades.

The combustion of hydrocarbon fuel in the air generates mainly carbon dioxide (CO_2) and water (H_2O). However, the combustion engines are not totally efficient, which means that the fuel is not totally burned. In this process the product of the combustion is more complex and could be constituted by hydrocarbons and others organic compounds, carbon monoxide (CO) and particles (PM) that contain carbon and other pollutants. On the other hand, the combustion conditions – high pressures and temperatures – originate partial oxidation of the nitrogen present in the air and in the fuel, forming oxides of nitrogen (mainly nitric oxide and some nitrogen dioxides) conventionally designated by NO_x.

Many of the atmospheric pollutants once emitted from the road vehicles react with the components of the air or react together and form the so-called secondary pollutant [5]. Due to the dispersion effect happened during the reaction, the concentration of the secondary pollutants doesn't usually reach maximum values near to the emission source. The impact can however extend to great areas not confined to the area of the road traffic.

As previously referred, atmospheric pollutants can also result from industrial sources and domestic dispersed sources. In a 1999 study for the United Kingdom [6] the average contribution of the road traffic was determined, as illustrated in Figure 1.

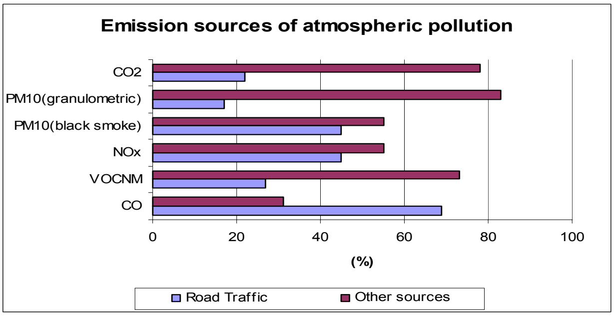

Figure 1: Contribution of the road traffic and other sources for the atmospheric pollution (adapted from [5]).

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In areas with high flow of heavy traffic, these percentages can be much higher. Inversely, in areas with low or insignificant traffic flow and with other sources such as industries or power generation plants those percentages can locate much below the pointed average to United Kingdom.

Air pollution caused by road traffic is the most often nuisance cited by roadside residents. For existing roads, it is first of all necessary to define the magnitude of the problem. New infrastructure can improve the surrounding area by easing traffic flow on existing roads. Hence the construction of new roads can bring about environmental benefits through a better distribution of traffic flows in the network and the various associated transport systems. The quantitative evaluation of traffic air pollution levels is the basis on which air pollution control policies stand.

Traffic air pollution levels can be evaluated by two different means: measurements and prediction. The measurement method is only feasible when applied to existent situations; the prediction methods are used with advantage from the very start of the planning process to the final detailed design of air pollution abatement measures.

Prediction methods have proved to be very useful and applied in a wide range of air pollution situations. When a calculation method is used, a large number of scenarios can be greeted by introducing different traffic flows, several types of vehicles, variable number of reception points, and air pollution abatement measures designs. By contrast, measurements results give information only about a very limited situation (the specific traffic and meteorological condition at the time the measurements are made).

There are available in the market numerous dispersion models, which constitute an important toolbox in the simulation of the air pollution situation. The model adopted for this research, was developed by CERC in the United Kingdom. This model has been used in over half of the pollution pilot studies carried out recently in UK [7]. It uses a parameterization of the boundary layer physics in terms of boundary layer depth and Monin-Obukhov length and uses a skewed-Gaussian concentration profile in convective meteorological conditions. In stable and neutral meteorological conditions the model assumes for the distribution of the concentration profile a Gaussian plume with reflection at ground and inversion layer.

The dispersion model has a methodological processor which uses the input variables, typically day of the year, time of the day, cloud cover, wind speed and temperature, to calculate the parameters for use in the model such as boundary layer depth and Monin-Obukhov length. The model does not take into account anthropogenic heat sources and the effect of the increased roughness in towns and cities.

An additional and important feature of the dispersion model, which makes suitable modelling in urban environment, is the inclusion of the chemistry scheme making possible the calculation of the chemical reaction between nitric oxide, nitrogen dioxide, ozone and volatile organic compounds in the atmosphere.

3 Evaluating critical air pollution disturbances zones in Viana do Castelo

The study undertaken aimed evaluating critical air pollution disturbance zones in the Portuguese city of Viana do Castelo, located on the northwest seaside. This is a mid-sized city, which has a population of 36.544 inhabitants living in an overall area of 37,04 Km^2. The most remarkable air pollution source is a main road that crosses the city dividing it in two parts.

Based in traffic data and in physical characteristics of the area, horizontal maps of four main pollutants were created: NO_2, C_6H_6, PM_{10} and O_3. A range of numerical models were used to produce results. The ADMS-Urban model was used for the pollutants dispersion, the Hills model was used to calculate air flow and turbulence over complex terrain, including the effects of variable surface roughness [8] and the COPERT4 [9] based on CORINAIR v.5 [10] was used to estimate traffic emissions.

The dispersion model, which is linked to a GIS (Geographical Information System), has been extensively validated in several works present in the literature [6, 7].

3.1 Calculation of horizontal air pollution maps

The modelling of dispersion of air pollution in built-up urban areas must integrate all the parameters which influence the dispersion, among others, the topography, the site, and meteorological condition like the wind and the heterogeneousness of the atmosphere.

For the sources characterization, and considering that Viana do Castelo is a touristy seaside city, two traffic counting campaigns were carried out, one in winter time and another one in summer time, of which resulted the data for two scenarios. Each campaign included most of the city streets and traffic was counted round-the-clock in a typical week day.

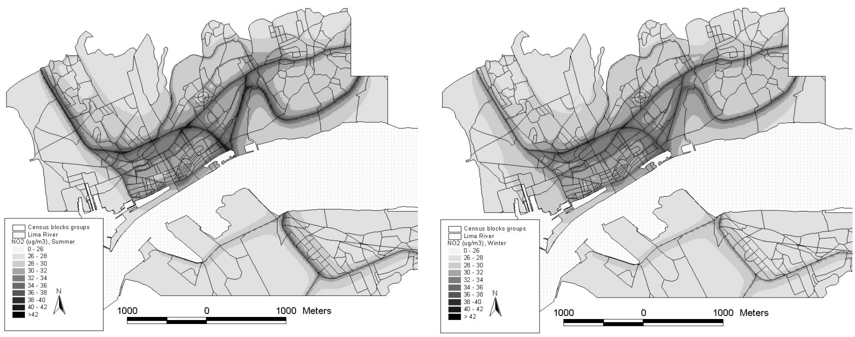
A full survey, including topographic characteristics, location of reception points (points for which the air pollutants are to be calculated), surface roughness and the specification of the emission sources, cross and longitudinal profiles (for canyon roads) was carried out for the whole city.

Taking the data gathered, the model was used to produce horizontal maps of four important urban air pollutants (C_6H_6, NO_2, PM_{10} and O_3) for winter and summer traffic-scenarios. The following calculation parameters were adopted:

Meteorological conditions: Data supplied by the Portuguese Institute of Meteorology (hourly)
Monin-Obukhov length: 30 m
Surface roughness: 0,5 m
Emissions inventory: database prepared for Viana do Castelo including road sources and industrial sources
Background file: annual average background concentration of NO_2, CO, PM_{10} and O_3 at background monitoring sites [11]
Average speed: variable

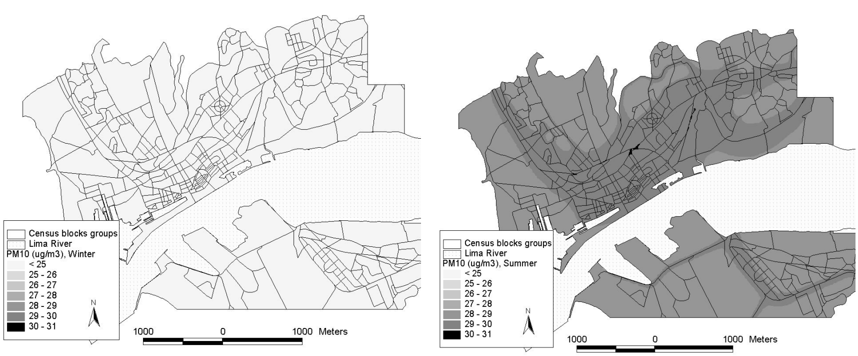
Main and secondary roads were modelled explicitly, as were major point industrial sources. Two single profiles were developed to represent the hourly variation of traffics flows on all the roads for the winter and summer scenario. The maps of the concentrations of the pollutants should be understood as the average situation of the atmospheric pollution, i.e. representative maps of one year, winter and summer scenarios.

Figures 2–5 show the NO_2, PM_{10}, O_3 and C_6H_6 maps, respectively, obtained for summer and winter scenario.



(a) summer scenario (b) winter scenario

Figure 2: Air pollution map, NO_2.



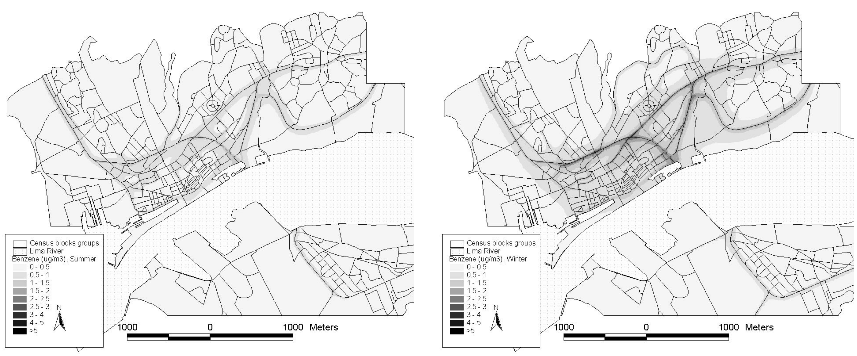
(a) summer scenario (b) winter scenario

Figure 3: Air pollution map, PM_{10}.

Results presented in Figures 2–5 reveal concentrations over de legal limits only for NO_2. For the other pollutants (PM_{10}, C_6H_6 and O_3) values in Viana do Castelo are well below the limits. The following sub-chapters aims to identifying the critical zones, both in terms of air quality levels, based on the pollutant with concentrations over the legal limit (NO_2) and people exposure to this kind of pollution.

(a) summer scenario (b) winter scenario

Figure 4: Air pollution map, O_3.



(a) summer scenario (b) winter scenario

Figure 5: Air pollution map, Benzene.

3.2 Overlay of air pollution maps on population

The 2001 population data obtained from the Census Bureau CENSO2001 and georeferenced to the smallest geographical spatial unit available – the census block – was stored in a topological GIS coverage and overlaid together with the NO_2 maps in order to find out the percentage of people subjected to relevant ranges of the several species of pollutant. For this purpose, a uniform distribution of the population within the blocks was assumed. The results can be observed in Table 2.

3.3 Air pollution criticality zones

At this point, the air pollution maps, may be weighted by the population in order to identify problematic zones.

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Table 2: Population exposed to NO_2.

Ranges of NO_2 (µg/m^3)	Winter scenario		Summer scenario	
	Population	%	Population	%
[0;26]	1601	5,61%	706	2,47%
[26;27]	6051	21,19%	5352	18,74%
[28;29]	6480	22,69%	5975	20,92%
[29;30]	4504	15,77%	5054	17,70%
[30;31]	3851	13,48%	4089	14,32%
[31;32]	2105	7,37%	2781	9,74%
[32;33]	1747	6,12%	1773	6,21%
[33;34]	973	3,41%	1025	3,59%
[34;35]	586	2,05%	724	2,54%
[35;36]	340	1,19%	435	1,52%
[36;37]	191	0,67%	253	0,89%
[37;38]	81	0,28%	209	0,73%
[38;39]	38	0,13%	103	0,36%
[39;40]	10	0,04%	51	0,18%
[40;41]	1	0,00%	27	0,09%
[41;42]	0	0,00%	2	0,01%

(a) summer scenario (b) winter scenario

Figure 6: Air pollution map, PM_{10}.

The index conflict zones of air pollution, denoted *C (equation 1)*, is given by the concentration (µg/m^3 NO_2) deviation to the legal limit, *DL*, multiplied by the population living in that zone PopD:

$$C = PopD \times DL \quad (1)$$

The use of the deviation to the legal limit instead of the actual concentration (µg/m^3 NO_2) value is due to the fact that the first considers the Portuguese annual limit values for the protection of human health.

The calculation of the index of conflict zones of air pollution *C* for the study area, within the GIS environment, resulted in the maps of conflict zones for summer and winter scenarios presented in Figure 6.

4 Discussion and conclusions

The first conclusion reveled from this study is that Viana do Castelo has indeed a good air quality.

Results presented in figures 2–5 reveal concentrations over de legal limits only for the NO_2 specie. For the other species (PM_{10}, C_6H_6 and O_3) the concentrations are well below the legal limits. However the same maps show the existence of a ring around the historical downtown where the air pollution levels are substantially superior. This ring includes: Avenida 25 de Abril (east-north), Rua dos Bombeiros Voluntários (north-west), Avenida dos Combatentes (west-south), and Avenida Marginal (south-east).

Inversely, the air quality within the historical center is quite good as it shows values clearly under the limits. This high quality is due to the severe traffic limitations imposed by the municipality in this zone.

Figures 2–4 show that the concentrations of PM_{10}, NO_2 and Benzene are higher near the sources, i.e. in the areas adjacent to the roads of heavy traffic. The same doesn't happen with Ozone (Figure 5), a secondary pollutant, where highest concentrations happen far away from the emission sources.

Overall, for the study area and both summer and winter scenarios, less than 1% of the population is exposed to a concentration over 40 $\mu g/m^3$ of NO_2.

The air pollution and population values, combined through an air pollution criticality index, revealed the existence of three criticality zones, as show in Figure 6. These zones should assume a first priority status when it comes to developing an air pollution mitigation plan.

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