Alert System in evaluation of risk exposure due to pollution caused by PM$_{10}$ in Lisbon city

Ana Rita C. Oliveira

Mestrado Integrado em Engenharia Biomédica
Instituto Superior Técnico, Lisboa, Portugal
ana.rita.acores@gmail.com

Supervisors: Amílcar Oliveira Soares (Instituto Superior Técnico, Universidade Técnica de Lisboa, Portugal) e Graça Oliveira (Faculdade de Medicina de Lisboa, Universidade de Lisboa, Portugal)

Abstract: Hundreds of millions of people suffer from (chronic) respiratory diseases in the world, and in Portugal these are the third cause of death. Urban air pollution due to PM$_{10}$ is one of the most important factors of the incidence and prevalence of those diseases and the increase of morbidity and mortality, with children and the elderly as the most affected groups. The aim of this work is to create an alert system, for all of North Lisbon Metropolitan Area (NLMA), based on the knowledge of the public health impact of PM$_{10}$ and on the use of the geostatistical model DSS in the characterization of dispersion of that pollutant. This study was conducted with data of 2007. Firstly, daily cartographic maps of the concentration of PM$_{10}$ were calculated by simulation; then maps that represent the maximum number registered of consecutive days with high levels of PM$_{10}$ were calculated; finally these risk factors were intersected with population density maps in the same area. The results showed that the Lisbon city centre and downtown is the most polluted area of NLMA, whereby their inhabitants are at higher risk. The admissions to the emergency service, in the year 2007 and 2008, at Santa Maria Hospital revealed a good correlation with the levels of PM$_{10}$ (with $\rho=0.713$ after the fourth fortnight and $\rho=0.734$ after the third, in year 2007 and 2008, respectively), fifteen days after exposure, which allow to consider the alert system proposed as a potentially good indicator of risk of exposure to pollution of NLMA inhabitants.

Keywords: Respiratory diseases; PM$_{10}$; North Lisbon Metropolitan Area; cartographic maps; population density; alert system.

I. INTRODUCTION

Respiratory diseases, often under-diagnosed, are the third cause of death and represent 13% of the total annual deaths in Portugal. Thereby, in respect to life quality, morbidity, mortality and costs (mainly due to hospitalization), those diseases are a relevant burden to our country, and they do not show a trend to decrease [2].

Exterior air pollution has been identified as one of the most important risk factors in development and exacerbation of respiratory pathologies, mainly in big cities. In Portugal, it is estimated that mortality due to secondary effects caused by air pollution reaches 4000 cases per year [2].

In this work we propose an alert system to evaluate the risk that Lisbon region inhabitants are exposed to, due to pollution associated with PM$_{10}$ levels. Thus, firstly the concentration of inhalable particles in the air will be characterized in space and time in NLMA, during the year 2007. Secondly the maximum number of consecutive days will be represented as a risk indicator associated with the pollutants’ levels. Finally the resident population in the interest area was evaluated based on population density maps that will constitute the third and last part of the alert system.

The system was finally validated through the bivariate analysis between the number of admissions of asthmatic children to the emergency service of Santa Maria hospital (SMH) and the levels of pollution (of monitoring station of Entre Campos) in the years 2007 and 2008.

II. THEORETICAL BACKGROUND

A. Respiratory system and risk factors associated with pathology development

Respiration is the process by which the human body cells obtain oxygen (O$_2$) and eliminate the carbon dioxide (CO$_2$) which results from their metabolism, without which humans cannot survive. These changes are made through the respiratory system, which is the only system of the human body that constantly interacts directly with the exterior. Thus, this system is provided with defence mechanisms to fight potential aggressors...
in the air. When these mechanisms fail, pathologies in the respiratory system occur.

Risk factors include urban air pollution which takes on an important role in the development of symptoms and respiratory diseases. In particular, inhalable particles (PM$_{10}$) have been identified as the pollutant which affects public health the most in the long-run [7]. This is why we are only going to focus on this pollutant.

B. Effects of PM$_{10}$ in human health

Particulate matter is composed of a mix of particles that can have aerodynamic dimensions inferior or superior to 10 µm; however, the particles inferior to 10µm (PM$_{10}$) are the most aggressive to the respiratory system, because they are not blocked by the hairs and ciliate cells of the upper airways, which means they may be inhaled, unlike the others [4].

PM$_{10}$ can cause damages to the pulmonary function, not just acting directly, but as transporters of other harmful substances to the lungs, as other pollutants or allergens [5].

As regards respiratory symptoms, the exposure to PM$_{10}$ can lead to an increase in or prevalence of symptoms of hiper-secretion of mucus and dyspnoea and diagnosis of chronic bronchitis and emphysema or chronic obstructive pulmonary disease (COPD) in areas with high levels of pollution caused by inhalable particles [3].

Several studies have shown consistently that the rates of asthmatic bronchitis and symptoms associated to asthmatic bronchitis are higher in children who live in very polluted areas when compared to children that live in less polluted areas [6].

High levels of PM$_{10}$ cause an increase of respiratory difficulties on individuals suffering from asthma, COPD and others, and can also lead to the premature death of elderly people with previous pulmonary or cardiac diseases.

The effects of the referred pollutant are associated with two types of exposure [9]: short-term and long-term. In the first, respiratory symptoms can occur (like cough, wheezing, and others), inflammatory reactions of the lungs, adverse effects on cardiovascular system, increase in hospital admissions and also an increase in medication usage.

In long-term exposure there is a risk of increase in respiratory symptoms of the lower respiratory tract, reduction in lung function in adults and children, exacerbation of COPD and reduction of life expectancy, mainly due to cardiopulmonary mortality and probably due to lung cancer.

C. Legislation on pollution levels

Facing the high pollution levels and their adverse effect on public health, the responsible entities have been taking measures with the purpose of lowering these numbers. With that purpose in mind, the current legislation [11] e [12] in Portugal today states that the PM$_{10}$ should not be over 50µg/m$^3$ (the value cannot be exceeded more than 35 times a year) and that the annual average is below 40µg/m$^3$.

D. Dispersion Models

The current existing models to characterize the concentration of pollutants in the air can be split in to two categories: The deterministic and the probabilistic models. The first one (the Gaussian Plume Model for example) reflects the physical phenomenon behind the transportation of air pollutants in the atmosphere. That is why the deterministic model is sensible to the local topography and the variability of the atmosphere, and because of this they can not be used in non-homogenous and complex conditions, like urban areas.

The probabilistic models represent the most recent evolution in this field and constitute the alternative to the use of deterministic models in the prediction of non-linear complex systems. One example of this type of models are neural networks, commonly used in short term prediction and dynamic characterization of complex systems; and the geostatistical models witch have been used in the characterization of an historic air pollution state of a certain urban area.

In this paper we will use a geostatistical model – Direct Sequential Simulation – to characterize the concentration, in time and space, of inhalable particles.

III. METHODOLOGY

A. Data Sets

The data set used in the present work, as well as the geographical localization of the monitoring stations were obtained in the online database QualAr from Agência Portuguesa do Ambiente [10], available at: http://www.qualar.org/

Since the year 2007 was the last year in which data was available online, that was the year analysed. As regards monitoring stations, only the measurements of eleven stations placed in the north Lisbon metropolitan area (NLMA) were used because the rest of the stations didn’t have data at all or the number of data was insignificant in comparison with the number of data in the rest of the stations.

The daily number of the emergency service admissions due to asthma, in the years 2007 and 2008, as well as PM10 levels of monitoring station of Entre Campos of 2008, constitutes the data used in validation of the alert system, and it was obtained in Santa Maria hospital.

B. Exploratory analysis

Based on the data set and the localization of the monitoring stations, the area chosen consists of the largest possible area containing the eleven monitoring stations (figure 1)
The measurements of PM$_{10}$ concentration, during year 2007, constitute the sample used in simulation of PM$_{10}$ concentration in all of the selected area.

Before simulation, the exploratory analysis and spatial and time continuity of the sample were obtained with the intent to identify main space-time patterns of dispersion and identify homogeneous periods. Thus according to the features of PM$_{10}$ values, the year was divided into 3 groups of four months. The first period corresponds to months of January to April; the second May to August and the third to the last four months of the year. Each period was analysed individually.

What is more, PM$_{10}$ concentration values of the monitoring station in Alfragide didn’t show any correlation with the rest of the monitoring stations and for this reason the measurements of that station were not used in this study.

C. Univariate Statistics and Variography

Before simulation it was important to analyse the univariate statistics, witch allowed for the analysis of the histogram and distribution function, of each period.

The variograms were also obtained with two directions: (0;90) e (0;0). The first direction was used to represent the relation between days of the period and the second direction was used to represent the relation in space between monitoring stations. The adjusted model in all directions of the three periods was a spherical model.

D. DSS model in levels of PM$_{10}$ cartography

Using the Direct Sequential Simulation model we obtained 20 equally probable realizations for each period, after which the average of the 20 simulations were calculated, which obtained a result of 120 maps of levels of PM$_{10}$ for the first period (corresponding to the 120 days of the period), 123 maps for the second period and 122 maps for the third period.

E. Number of consecutive days

Based on the average of the 20 simulations of each period, we developed an application in Microsoft Visual Basic to calculate the periods of two or more days of consecutive days (and the duration) with PM$_{10}$ concentration values above a threshold, in each pixel of the maps. The application allowed to calculate the maximum number registered of consecutive days as well, in order to represent the results in cartographic maps.

F. Geographic Information Systems: arcGIS

All maps obtained were treated in a geographic information system – arcGIS – through which it was possible to georeference and cut the maps according to the interest area. In these results the localization of monitoring stations as well as the limits of each parish were represented.

In the software the coordinate system used was Lisboa – hayford Gauss IgeoE, with a resolution of 100 by 100 meters.

G. Population Density

The number of inhabitants for each age-group of the census 2001, from INE, was represented in population density maps to age groups of children (below 4 years old and below 14 years old) and elderly (older than 65 years). These maps were built in arcGIS software and once again the coordinate system was the same: Lisboa – hayford Gauss IgeoE.

H. Alert System Validation

The alert system was validated through the bivariate analysis between the number of admissions of children diagnosed with asthma to the emergency service of SMH, and the levels of PM$_{10}$ in the air. Data from years 2007 and 2008 were analysed. And in that analysis correlation coefficients were calculated and time series were represented.

The age characteristics of child population analysed were: minimum age of 0 years, medium age of 6 years and maximum age of 15 years, in 2007, and 16 years, in 2008.

IV. RESULTS AND DISCUSSION

The alert system presented in this work integrates three parts essentially: the space-time characterization of the levels of PM$_{10}$ in NLMA, in the year 2007; a risk indicator associated to the pollution levels and in this case the indicator used was the maximum number of consecutive days with PM$_{10}$ values above 50 µg/m$^3$; and population density maps of age groups at higher risk.

The following results are the main results obtained for each part of the alert system.
Space-time characterization of PM$_{10}$ concentration in the air

As regards this part, the figures 2 to 7 represent only two examples for each period from the obtained results, corresponding to the state of the air for one day.

Figure 2 – PM$_{10}$ concentration in the air for the 17th day of the first period (corresponding to the 17th day of January of 2007), in NLMA selected.

Figure 3 – PM$_{10}$ concentration in the air for the 46th day of the first period (corresponding to the 15th day of February of 2007), in NLMA selected.

Figure 4 – PM$_{10}$ concentration in the air for the 72nd day of the second period (corresponding to the 11th day of January of 2007), in NLMA selected.

Figure 5 – PM$_{10}$ concentration in the air for the 120th day of the second period (corresponding to the 28th day of August of 2007), in NLMA selected.

Figure 6 – PM$_{10}$ concentration in the air for the 21st day of the third period (corresponding to the 21st day of September of 2007), in NLMA selected.

Figure 7 – PM$_{10}$ concentration in the air for the 47th day of the third period (corresponding to the 17th day of October of 2007), in NLMA selected.

The results presented showed that Lisbon County registered, in general, the highest levels of PM$_{10}$ in the air. In particular, Lisbon centre and downtown (mainly the areas nearest Avenida da Liberdade) showed the worst results of air quality.
Risk indicator associated to pollutants concentration: maximum number of consecutive days

In this section, we present the results of maximum number of consecutive days, with values above the legal limit.

Figure 8 – Representation of the maximum number of consecutive days with PM$_{10}$ concentration values above 50µg/m$^3$, for the first period.

The figure above shows that all of Lisbon city registered a period of eleven days, approximately, with consecutive days with PM$_{10}$ concentrations above 50µg/m$^3$. The Lisbon centre and downtown showed the most elevated period, with more than 13 consecutive days, hitting a period of 21 consecutive days in some areas. What is more, the Lisbon city surroundings showed 8 to 10 consecutive days with high levels of pollution. This means that the inhabitants of Lisbon where exposed for several days to high levels of pollution.

Second period (figure 9) shows better results than first period.

Figure 9 – Representation of the maximum number of consecutive days with PM$_{10}$ concentration values above 50µg/m$^3$, for the second period.

As we can see in figure 9, the Lisbon city centre registered a maximum number of consecutive days of 3 to 4 days. Nevertheless it was a small area, between Avenida da Liberdade and Restelo stations with a number of 7 days (or a week) with high levels.

For the third and last period, figure 10 shows the result obtained.

Figure 10 – Representation of the maximum number of consecutive days with PM$_{10}$ concentration values above 50µg/m$^3$, for the third period.

As we can see, only Lisbon County presented consecutive days with PM$_{10}$ concentrations above 50µg/m$^3$. However the Lisbon city centre showed more than 15 days with elevated levels of inhalable particles, which means that for two weeks, Lisbon’s inhabitants were exposed to high levels of pollution.

All the results show that in the year 2007 there were considerable periods of consecutive days with levels of pollution above the legal limit.

We have seen that the areas with the highest periods of consecutive days were Lisbon County, in particular Lisbon city centre and downtown, which were the same areas identified previously with the highest levels of pollution.

Population Density

The maps of population density obtained for the age groups of children (below 4 years old and below 14 years old) and the elderly (above 65 years old) are shown in figures 11 to 13.

Figure 11 – Representation of population density for each parish, for age group below 4 years old.
According to the maps of figures 11 and 12 we can see that the population density is similar between the two age groups.

The major population densities are in some parishes of Lisbon centre and downtown and some of the parishes nearest to Lisbon city in the Amadora, Sintra, Odivelas and Loures Counties.

As regards age group 65 years old and older, we can see that the largest number of elderly resides in some parishes of Lisbon centre and downtown, essentially.

Confronting these results with the previously results obtained with respect to levels of PM$_{10}$ in the air, we can obviously see that the people, mainly children and elderly living in the Lisbon city centre and downtown make up for the population at higher risk. Thus, the inhabitants of those areas possess higher risks of incidence and prevalence of symptoms and respiratory diseases, increase in morbidity and premature death due to respiratory causes.

**Alert System validation**

To validate the use of the proposed alert system, we choose the daily number of admissions at emergency service of SMH in the years 2007 and 2008.

The monitoring stations located at the SMH catchment area are Entre Campos, Odivelas and Loures. So the data used for the alert system validation will be composed only of the measurements of those stations.

The graphics showed below represent the average fortnightly (to eliminate the large oscillations) of each monitoring station mentioned above.

Analysing the graphic we can see that the values measured at each station are highly correlated ($\rho=0.91$ between stations Loures and Entre Campos, $\rho=0.92$ between stations Loures and Odivelas and $\rho=0.96$ between stations Entre Campos and Odivelas).

On the other hand, the Entre Campos station shows the highest averages, so we are only going to use the values of that station, although any other station data could be used because of the correlation coefficients obtained.

The next figure presents the time series of the fortnightly average of the PM$_{10}$ concentration of the Entre Campos station; the respective consecutive days with values higher than 49µg/m$^3$, for each fortnight (multiplied by a 10 factor); and the fortnightly sum of the number of admissions of asthma. In this case the sum was calculated instead of the average in order to obtain significant values for comparison. Note that the time series of asthma sums start 15 days after time series of PM$_{10}$ levels.

The graphic in figure 15 shows that there is an increase in numbers of hospital admissions with the increase of pollution levels, fifteen days after exposure.

In order to better understand the relation between the two variables, the several correlation coefficients were calculated, eliminating the calculus of each coefficient one fortnight (from the beginning). At fortnight 4, $\rho=0.713$, and at fortnight 9, $\rho=0.811$, which indicates that only the first three weeks didn’t show a good correlation.

As regards the maximum number of consecutive days and the admissions number due to asthma, these
show that there is an increase in admissions fifteen days after, which continues to grow in the next fifteen days after that too, with an exposure to a number of consecutive days equal or superior to three days (after the forth fortnight). This relation is well observed at the end of the year, specifically after the 14th fortnight. This result emphasizes the importance of the use of periods of consecutive days as a risk indicator in the incidence and prevalence of exacerbation of health condition of asthmatic children.

We should note that at fortnight 9, the number of admissions decreased after a period of two consecutive days. This result may indicate that two days is an insignificant period in the exacerbation of health of asthmatic children.

As in the year 2007, only data from Entre Campos station of 2008 were analysed, in the same manner. Once again asthma admissions showed a better relation with pollution levels fifteen days after exposure. Figure 16 show the results obtained.

![Graph showing time series of admission numbers of asthma sum fortnightly, PM_{10} concentration measured in Entre Campos station and maximum number of consecutive days with concentration values higher than 49 \mu g/m^3, fortnightly (with the total number of asthmatic children on admission fifteen days after the beginning of PM_{10} average and number of consecutive days); year 2008.]

As respect to correlation coefficients, in the year 2008, the values obtained were lower compared with the results obtained in the year 2007: \( \rho = 0.611 \) after the third fortnight and \( \rho = 0.843 \) only after the fifteenth fortnight. Those results occurred due to an “anomalous” point at fourteenth fortnight, which an increase in pollution levels didn’t show an increase in asthma admissions, as were expected. So ignoring the influence of that point at correlation coefficients calculations the results showed a similar behave to 2007 results: with \( \rho = 0.734 \) after the third fortnight and \( \rho = 0.846 \) after the eleventh fortnight.

The existence of that point maybe due to the fact that period corresponds to school holidays and the most part of children may not have been exposed to that increase in air pollution, because they went out of town.

As regards maximum number of consecutive days and the admissions number due to asthma, the results were insufficient. Nevertheless, despite the fact that only two fortnights showed three consecutive days, the results show that there is an increase in admissions fifteen days after, which continues to grow in the next fifteen days after that too, once again.

V. CONCLUSIONS AND FURTHER WORKS

The number of emergency service admissions showed a positive association, fifteen days later, with the levels of pollution due to inhalable particles, in years 2007 and 2008, except for the first (four) fortnights of the year. Similarly, the number of consecutive days revealed itself to be extremely important in the exacerbation of the health condition of asthmatic children, especially in the year 2007. These results indicate that the prevalence of high levels of inhalable particles in the air is relevant for the aggravation of health of asthmatic children, validating too the choice of those results as a risk indicator associated with pollution levels in the air.

The results of bivariate analysis between the PM_{10} levels in the air and the admission numbers to the emergency service of SMH showed that the use of the obtained cartographic maps using a geostatistical model is potentially a good alert system to evaluate the risk that the inhabitants of the analysed area are exposed to, mainly asthmatic children.

On the other hand it is important to note that an important development of this work consists in the characterization of a better estimator of the lag period find (15 days) between the admission numbers and PM_{10} levels average, which is a very important “time” in the construction and management of the alert system.

The analysis of other pathologies associated to inhalable particles (as COPD or even mortality) or the evaluation of health effects at elderly people is a curious development in the alert system validation.

Other projects can be developed in subsequence to this one. The construction of the same alert system for another pollutant, as ozone; or even for another city with serious pollution problems; or a study to analyse the influence in air pollution on the construction of new highways in Lisbon region, as IC-19. These are just some examples of the work that may be developed in this area.

VI. REFERENCES


