Industrial contribution to the air quality of one mid-sized Portuguese city

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Abstract: 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 incompatibilities of uses. In urban environment the typical anthropogenic sources are mainly the road traffic and, when existing, the industrial activity. The present work was performed to attain the following objectives: to quantify the atmospheric emissions from the major industrial sources located in the city and its vicinity and to evaluate the influence of these industrial sources to the air quality of the city. A range of numerical models were used to produce the concentration maps: the ADMS-Urban model for the pollutants dispersion; the Hills model to calculate air flow and turbulence over complex terrain and the European Pollutant Emission Register to estimate the emission factors.

Key-Words: Urban air pollution; Air pollution modelling; Kraft pulp and paper mill

1 Introduction

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

The work developed in Viana do Castelo used local emission inventories to model concentrations of the key pollutants in the city, and the outputs included time series of predicted concentrations which were compared with measured data at monitoring sites. Predicted concentration includes time series at locations coincident with monitors and contour maps over the total calculation area.

The present work was performed to attain the following objectives:

- to quantify the atmospheric emissions from the major industrial sources located in the city and its vicinity.
- to evaluate the influence of these industrial sources to the air quality of the city.

The most remarkable air pollution industrial source is one pulp and paper mill (one IPPC mill) located in the vicinity of the city. In this context this paper will focus on this important source.

The air pollution involves the spectrum of activities causing the emission of substances or energy into the atmosphere, which negatively influence the quality and composition of air [1].

In most countries the environmental performance in industry has been and still is, strongly driven by regulation, including permits systems. In the European Union the Directive on Integrated Pollution Prevention and Control (IPPC) is the core legal instrument to confer a harmonized and integrated environmental permit system for major industrial installations [2]. In essence, the IPPC Directive is about minimising pollution from various industrial sources throughout the European Union [3].

Operators of industrial installations covered by Annex I of the IPPC Directive are required to obtain an environmental permit from the authorities in the EU countries [2].

The purpose of the IPPC Directive is to achieve integrated prevention and control of pollution arising from major industrial activities through, namely, the application of the best available techniques (BAT) concept.

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 concentration for the protection of human health [4,5]

Pollutant	Averaging period	Value
Nitrogen dioxides (NO_2)	Calendar year	40 µg/m3
Particulate matter (PM_{10})	Calendar year	40 µg/m3
Ozone (O_3)	8 hours (rolling average)	110 µg/m3
Sulphure dioxide (SO_2)	24 hours	125 µg/m3

2 Air Pollution. Industrial contribution

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 incompatibilities of uses.

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 (rainout and washout of the rain and snow) or dry deposition (adsorption of particles) [6,7].

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 source [6].

As referred, the industrial activities constitute one important source of air pollution. In particular, the environmental impacts of the manufacture of pulp and paper result from the pulping and bleaching processes. According to Word Bank [8] typical emission rates from kraft pulping process are 75–150 kilograms of particulate matter per metric ton (kg/t) of air-dried pulp produced (ADP: air-dried pulp is defined as 90% bone-dry fibre and 10% water); 0.3–3 kilograms of total reduced sulphur (TRS) per metric ton (kg/t) and 1–3 kilograms of nitrogen oxides per metric ton.

In Portugal paper manufacturing began in the end of the 14th century. However, the first mills appeared only in the beginning of the 18th century. It was the first country to manufacture chemical pulp form eucalyptus: using sulphite in 1923; and sulphate in 1957 [9]. Since that time production has been gradually increased with the construction of newer plants to face the demands from external markets.

At present, Kraft pulp is one of Portugal largest exports due to the availability of pine and eucalyptus forests in the country. The Pulp and Paper Sector's activity contributes strongly for the Portuguese economy growth, as it is a net exporter sector. The sector has an imports coverage rate of about 40% [9], contributing positively to the country's economy.

One of the most sensitive environmental impacts of the Kraft (sulphate) pulp mills is associated with the atmospheric pollution which are mainly composed of solid particulate, carbon monoxide, sulphure dioxide, nitrogen oxides, hydrogen sulphide and mercaptans, such as methylmercaptan, dimethylmercaptan and dimethyldisulphide [10,11].

The main stationary sources of emissions to the atmosphere occurring from the kraft process are associated to the production process: recovery boiler stacks, limestone kiln stacks and the stack from the smelt dissolving tank.

The particulate emissions are mainly composed of salts: from the recovery boiler and smelt tank stacks produces sodium salts and calcium salts from limestone kiln stack.

The sulphur dioxide is emitted from the recovery boiler as an oxidation product occurring in that unit. Carbon oxides are emitted as an oxidation product formed in the combustion units, such as recovery boiler, lime kiln and other auxiliary boilers.

The reduced sulphur compounds that contribute for the typical odour of these plants are mainly composed of mercaptans.

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 contrast, measurements results give information only about a very limited situation (the specific source and meteorological condition at the time the measurements are made).

Numerous dispersion models are available, 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 [12]. This model has been used in over half of the pollution pilot studies carried out in the UK [13,14]. It uses a parameterization of the boundary layer physics in terms of boundary layer depth and Monin-Obukhov length and use 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 [12].

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, wind direction 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.

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 Industrial contribution to the air quality of Viana do Castelo

The study undertaken aimed to evaluate the influence of the most important industrial sources to the air quality of a Portuguese city – Viana do Castelo, located in 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 Km2. The most remarkable air pollution industrial source is one pulp and paper mill located in the vicinity of the city (Fig. 1).

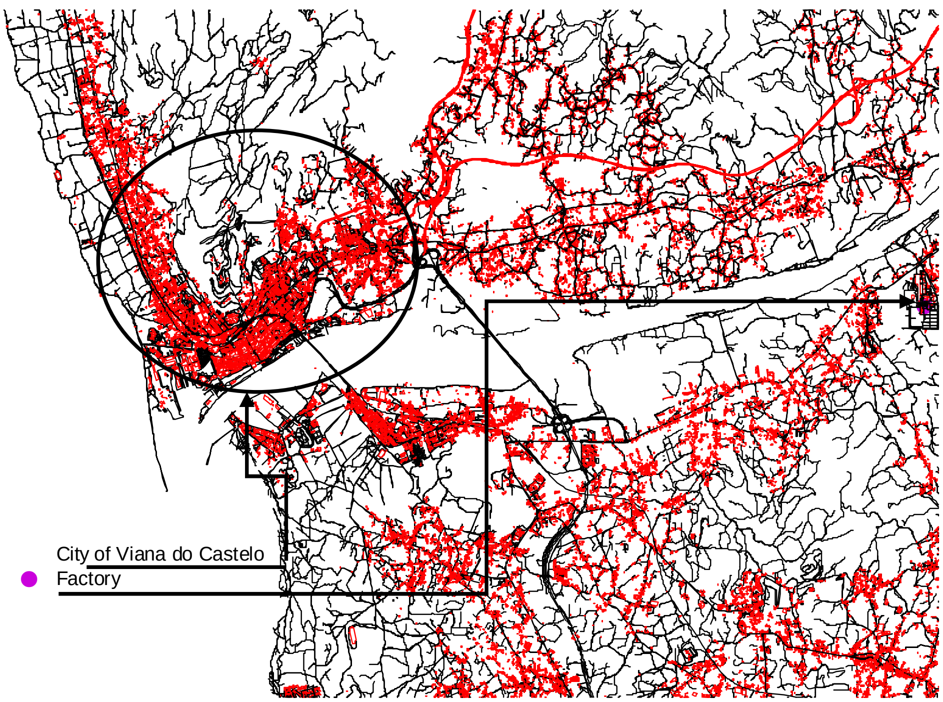


Fig.1 – Factory *vs*. Viana do Castelo location

The main products of this pulp and paper mill are unbleached sulphate eucalyptus and pine pulp, recovered paper pulp and kraftliner paper.

Based on emissions factors, and on physical characteristics of the area, horizontal maps of three main pollutants were created. 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 [12] and
- the EPER register [15] was used to calculate the emission factors of the factory.

The dispersion model, is linked to a GIS (Geographical Information System) platform for input and output data.

The methodology adopted for the validation of urban air dispersion model of Viana do Castelo was based in BOOT statistical approach [16]. The usually used BOOT statistics approach derives from that of Hanna and Paine [13] and employs a series of statistical measures comprising the mean, correlation, normal mean square error and fractional bias.

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.

A full survey, including topographic characteristics, surface roughness and the specification of the emission source, was carried out for the whole city.

Taking the data gathered, the model was used to produce horizontal maps of three important industrial air pollutants (NO_x, PM_{10} and SO_2).

The calculation parameters adopted are laid out on Table 2.

Table 2 – Calculation parameters adopted

Meteorological conditions	Data supplied by the Portuguese Institute of Meteorology (hourly) for one year
Monin-Obukhov length	30 m
Surface roughness	0.5 m
Emissions inventory	industrial source
Heigh of the maps	1.2 m

3.2 Emissions Data

In order to evaluate the influence of the pulp and paper mill to the air quality of the city of Viana do Castelo this pulp and paper mill was the unique contribution. This factory is one IPPC mill (Integrated Prevention and Pollution Control), and for that reason is forced to make the register EPER (European Pollutant Emission Register). The EPER is web available [16].

Table 3 shows the global emissions factors for the pulp and paper mill.

For the hourly average calculation was considered 15 days for stop-maintenance and 334 days of work. Since this factory works 24 hours a day, that period represents 8400 hours of work.

The factory was modelled as one point source that represents the stack.

Table 4 shows the global stack characteristics.

Table 3 – Global emissions for the pulp and paper mill

Pollutant	ton/year	kg/h
PM10	102.00	12.14
NOx	526.00	62.62
SOx	1030.00	122.62

Table 4 – Stack characteristics

Stack height [m]	93.15
Stack diameter [m]	3.60
Vertical velocity of release at source exit [m/s]	10.0
Temperature of the release [ºC]	160.0
Stack location	48196.85; 225674.13

3.3 Meteorological Data

It was used hourly sequential meteorological data supplied by the Portuguese Institute of Meteorology for the year of 2001.

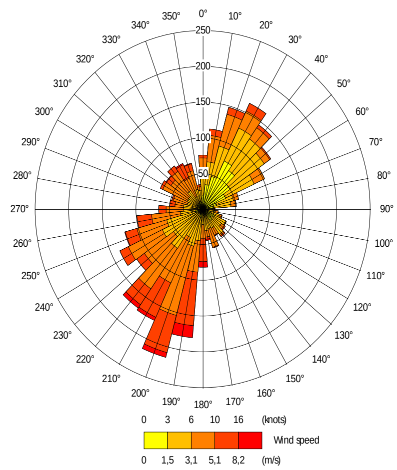
The summer scenario includes June, July, August and September (Julian days 152 to 273) and the winter scenario comprehends the remaining period of the year 2001.

The observed meteorological conditions show 20% of occurrences of clean sky and 13% of sky totally cloudy in the summer scenario. The winter scenario shows 10% of occurrences of sky completely clean and 28% of sky totally cloudy.

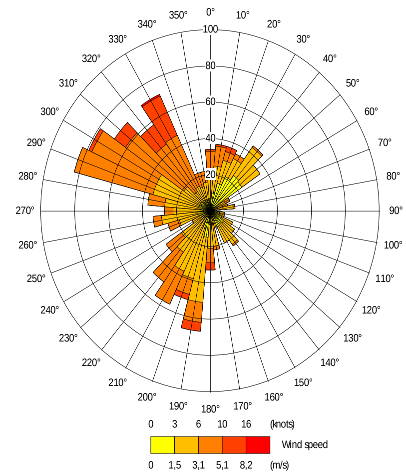
The average wind velocity oscillates between 0.8 and 8.9 m/s in the summer scenario and 0.8 and 12.8 m/s in the winter scenario.

The percentage of calm winds (veloc. <0.55m/s) during winter scenario was 19% and 20 % during summer scenario. In the modelling process was excluded hours of calm, hours of variable wind direction and unavailable data.

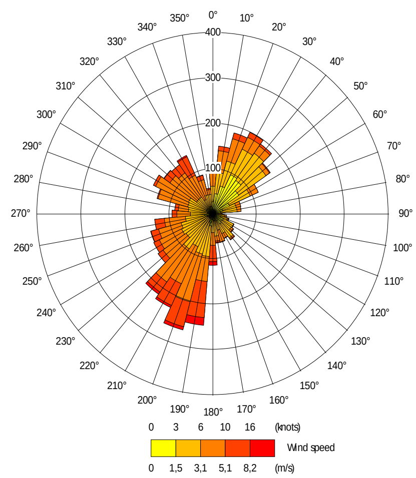
The Figure 2 compares the wind-roses of the three scenarios. The predominant wind direction in winter was Nor-Northeast/east and South-Southwest/South with a total of occurrences 22.2% and 17,4% respectively. The summer scenario reveals predominant wind direction from South/South-Southwest and from Oés-Northwest/ Northwest, with 19% and 24% of the total of the occurrences approximately and respectively.



a) winter scenario



b)summer scenario



c) Year long term average

Fig.2 – Wind-roses

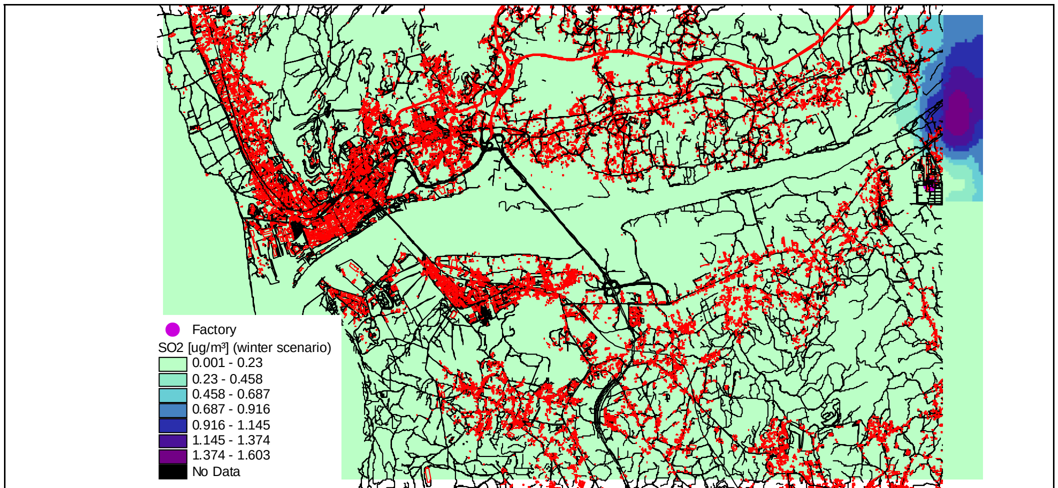
3.4 Calculation of horizontal air pollution maps

The maps of the concentrations of the pollutants should be understood as the average situation of the atmospheric pollution i.e. long term maps.

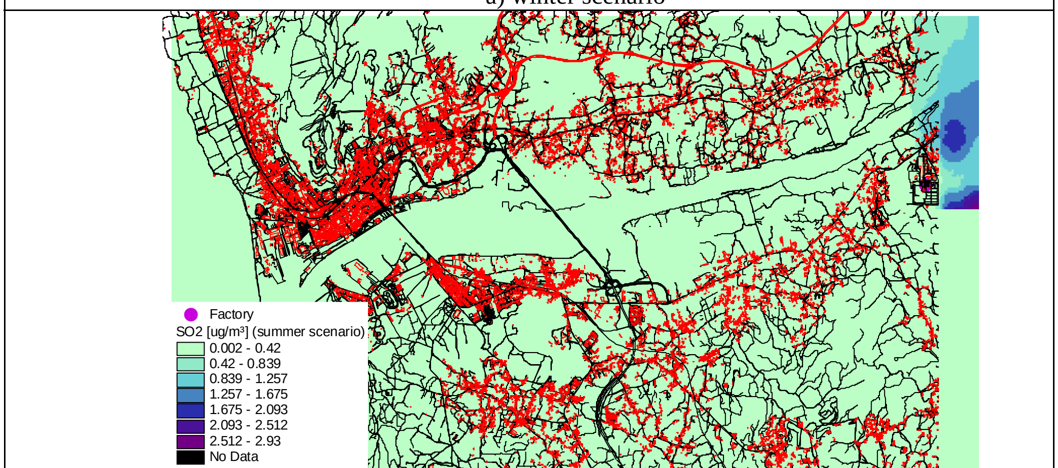
Due the variable characteristics of wind (velocity and direction) that generate the wind fields along the year, it was created three scenarios:

— The "year long term average" scenario represents one year.

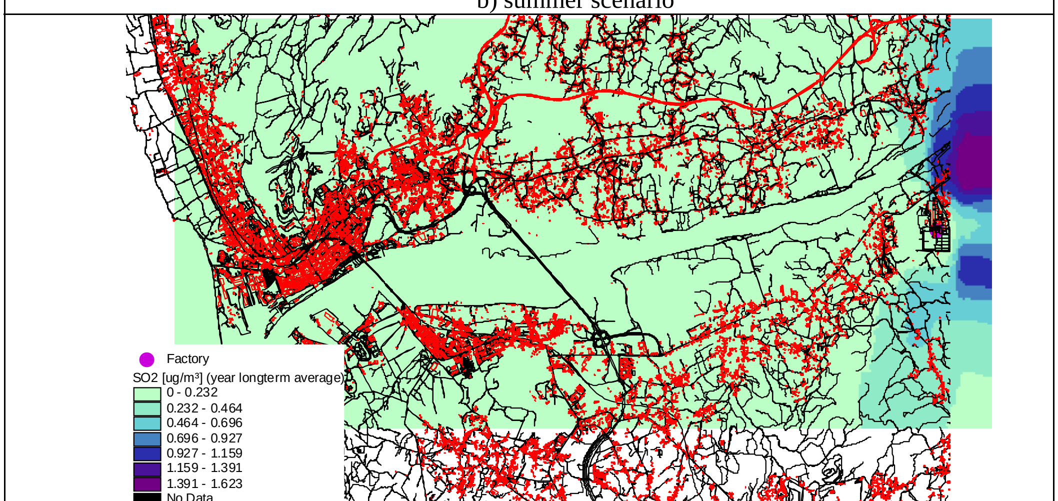
- The "summer scenario" represents the following period: Julian day from 152 to 273.
- The "winter scenario" comprehends the remaining period.



a) winter scenario

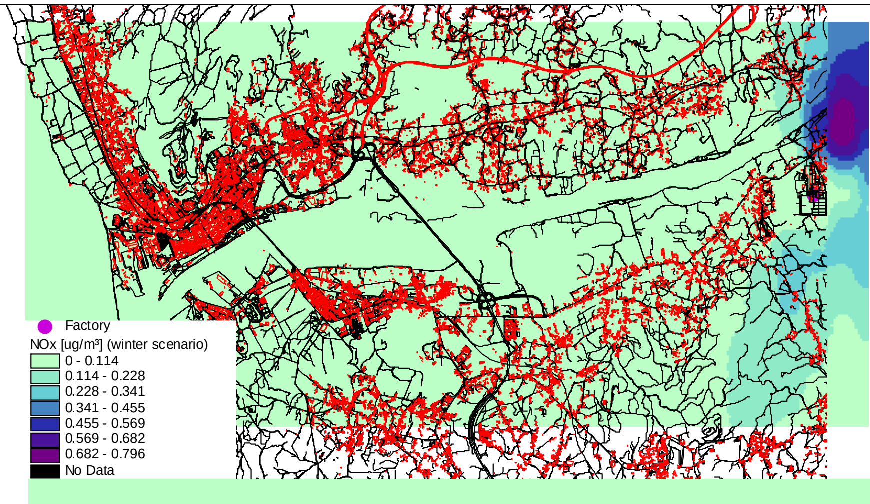


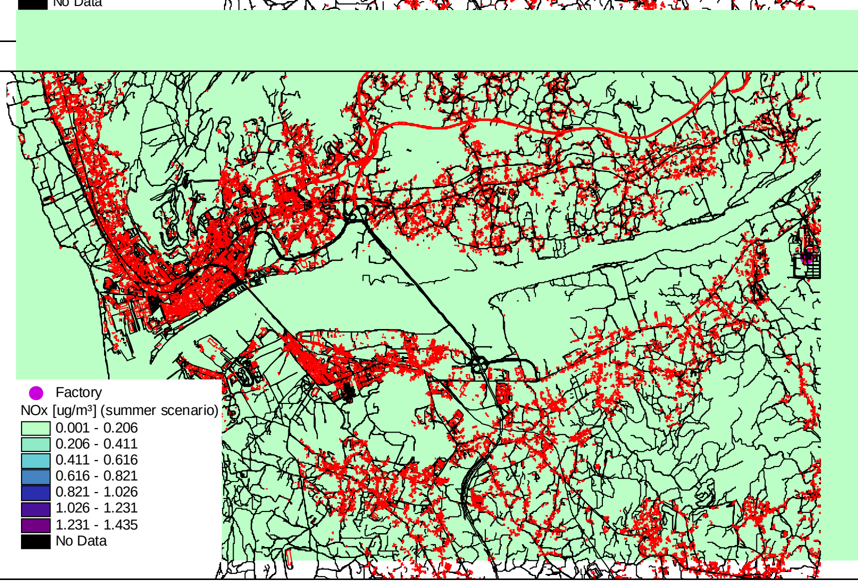
b) summer scenario



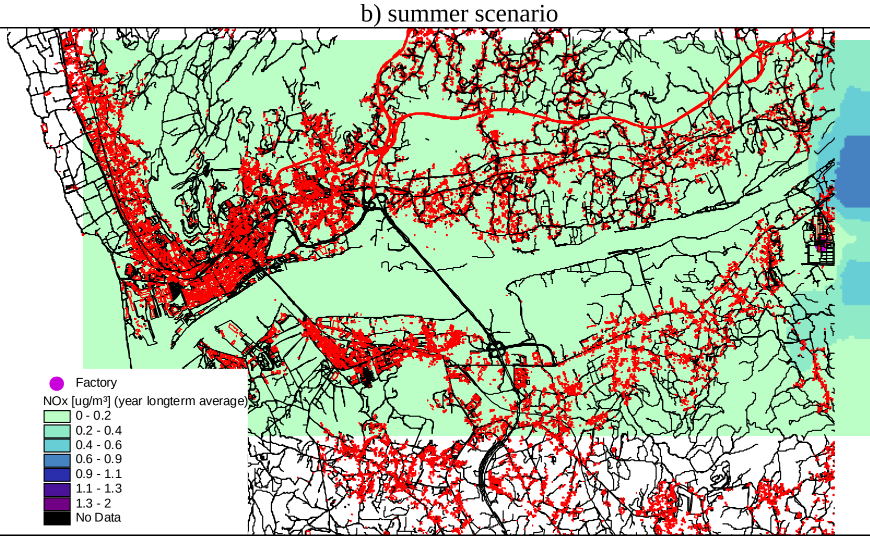
c) year long term average

Fig.3 – SO_2 concentration maps



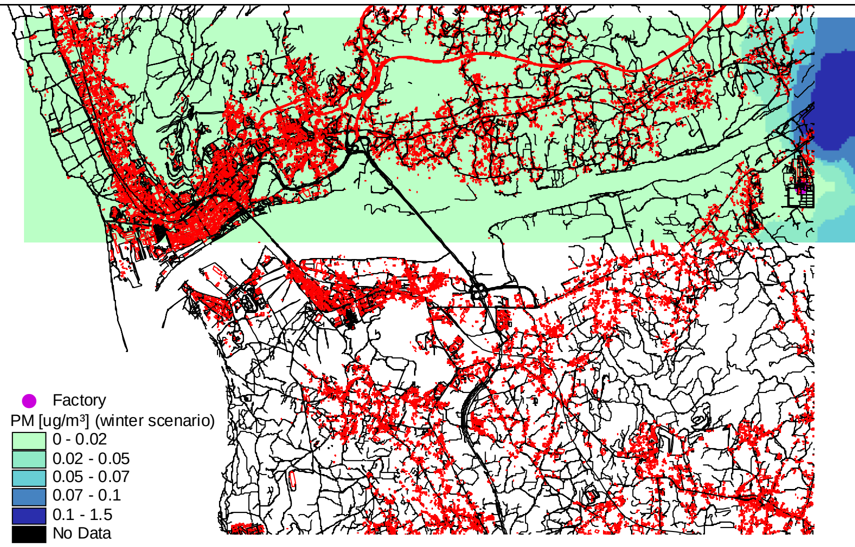


b) summer scenario

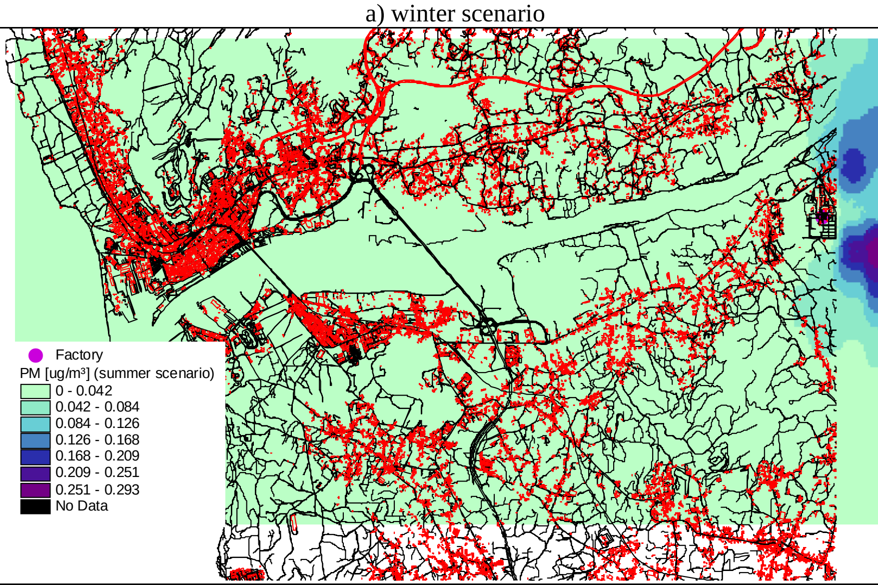


c) year long term average

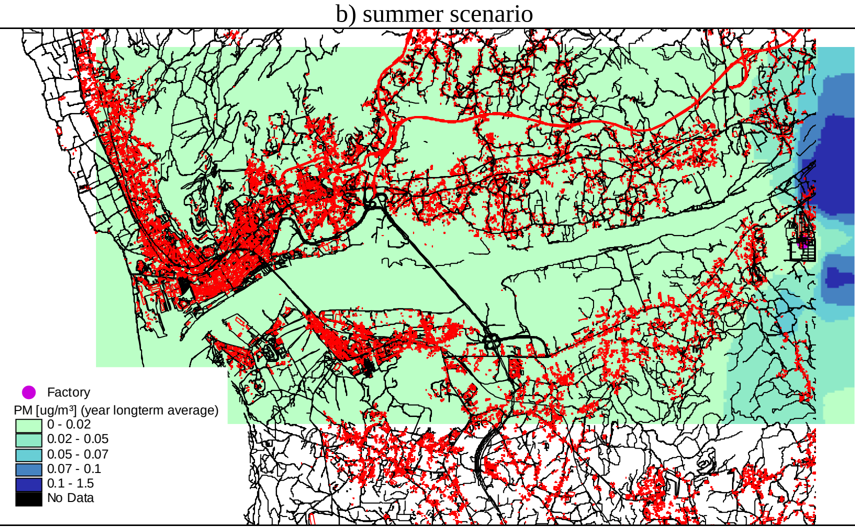
Fig.4 – NO_x concentration maps



a) winter scenario



b) summer scenario



c) year long term average

Fig.5 – PM_{10} concentration maps

Figures from 3 to 5 shows the SO_2, NO_x, and PM_{10} concentrations maps, respectively, obtained from the “winter scenario”, “summer scenario” and from the year 2001.

The results obtained (Figures 3 to 5) reveal concentrations below de legal limits for all pollutants modelled (PM10, SO2 and NOx) and the contribution of the industrial source to the air quality is low.

The air pollution maps show clearly the shape of the spread of the plume of pollutants generated of the three scenarios.

6 Discussion and Conclusion

We have evaluated the atmospheric concentrations of particulate matter, sulphite dioxide and nitrogen dioxides in the city of Viana do Castelo, both under the influence of one emission point that represent one pulp a paper mill located in the vicinity of that city.

Wind direction is the main factor that changes the trajectory, or path, of air pollutants from their source to any receptor. Wind speed and the distance from the source is determine the time it will take air pollutants to travel from source to receptor [17].

Due the variable characteristics of winds (velocity and direction) that generate the wind fields throughout the year, it was created three scenarios: The "year long term average" scenario, which represents the year 2001; the "summer scenario" which represents the period between June and September (2001); and the "winter scenario" that comprehend the remaining period of the year 2001.

The first conclusion of this study shows that the pulp and paper mill do not affect the air quality in the city of Viana do Castelo.

The Figures 3, 4 and 5 shows that the concentrations of SO_2, NO_x and PM_{10} are higher near the source, in downwind direction.

Depending on the meteorological condition the results show a clear influence on the near vicinity of the factory. As a consequence, the factory contributes with one additive concentration ranging from 0.02 to 1.5 $\mu g/m^3$ of PM_{10}; 0.23 to 1.6 $\mu g/m^3$ of SO_2 and 0.2 to 1.5 $\mu g/m^3$ of NO_x.

The spread of the plume of pollutants generated from the factory reveals a clear tendency to the southeast in the winter scenario and to the northeast in the summer scenario. In the long term concentrations maps the spread of the plume take the east tendency.

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