Air pollution from traffic, ships and industry in an Italian port

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Abstract

In the present study, the levels of NO_x, primary and secondary formed particulate matter (PM10, PM2.5) originating from the intensive commercial and industrial activities within the port zone of Ancona (Italy) were analysed. The data have been evaluated, calculating by a Weibull distribution approach, the hourly, or using a recoded time, statistics of the pollutants concentrations and meteorological parameters measured in an area situated in a zone of influence of the harbour area. This gave the opportunity to study the dependence of the processes on the local scale as well as the impact of the harbour area on the urban scale. The highest concentrations of PM generally occurred in the harbour area whereas the NO_2 was found to be higher in the urban area. The pollutant transport from the harbour and related to the local dispersive ventilation capacity can become important in episodic situations even in the facing urbanised area.

Keywords: PM10, PM2.5, NO_2, harbour area, urban air.

1 Introduction

Ancona is an Italian town surrounded by a busy sea and hilly streets, with a port for agricultural and industrial goods, traffic and passengers, and for fishing boats. Mineral and vegetable dust coming from the intensive commercial and industrial activities on vegetable seeds such as soybean, sunflower and castorbean add to the gaseous Volatile Organic Compounds (VOC), SO_2 and NO_x from heating and ships sailing around the harbour. The urban area is characterized by high population density and economic development. The resulting pollutant emissions place an increasing pressure on the air quality of this area. Whereas in the past the major reasons for poor air quality were

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industrial activity and domestic heating, nowadays as a result of the rapid increase in mobility an important amount of air pollutants comes from road traffic. This is particularly significant for the harbour area, where rapid rates of growth in heavy vehicle numbers is expected simply because transportation is an important infrastructural facility and plays a very important role in the overall development of the community. As the number of vehicles is increasing rapidly, it has started hindering the atmospheric purity correlated with the emission loads and meteorological conditions. The lognormal distribution has been widely used to represent the type of air pollutant concentration distribution and the parent frequency distribution gives good result for evaluating the mean concentration of pollutants (Kao and Friedlander [4]; Taylor et al. [6]; Horowitz and Barakat [3]; Yu and Chang [7]). In the present study, we relate the dispersal of PM10, Pm2.5, NO_x and SO_2 originating from industry, ships and traffic in the harbours of Ancona (Italy), relying on local data of meteorological conditions with the aim of assessing the dispersive capacity for this place which is environmentally fragile and health sensitive.

2 Characteristics of the study area, emission data and assumptions

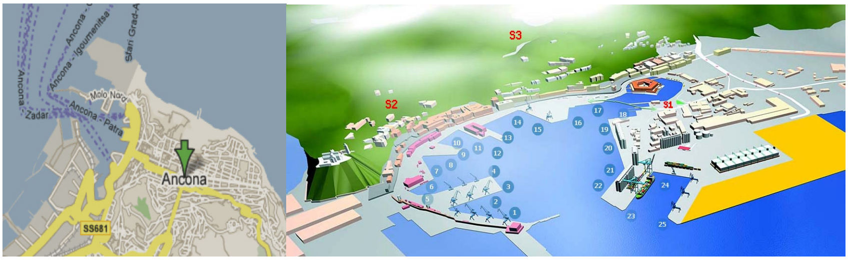
The city of Ancona with about one hundred thousand inhabitants is located at the Adriatic side of the Marche Region in Italy, with longitude between 43°37’00’’ and 43°36’21’’, and latitude between 13°30’2’’ and 13°27’21’’; its urban extension is approximately 2x2 square km. The city is surrounded by hills of approximately 300–500m height with only the North and East ends open to the Adriatic Sea. This natural topography has influence on the meteorological conditions determining the air pollution condition. The meteorological station furnishing the data used is located in the centre of the city. For the years 2005–2006 the annual rainfall reached 835 mm while the highest monthly rainfall was 112 mm during September 2006. January was the coolest month with a daily average temperature of 3°C, while in July the daily average reached 28°C in the year 2006. The annual mean wind speed was 3.5m/s with predominant wind directions of WNW, W, and NE.

Manufacturing of vegetable oil seed is the most air-polluting sector together with small and medium–sized manufacturing firms of towboats and yachts present in the harbour and its surroundings. In Fig. 1 a pictorial map of the area is shown, including the main industrial zones and monitoring stations.

Aerial emissions in the harbour originate from manoeuvring ships, activity at the dock, traffic and industrial manufacturing. Dock activity requires all the machinery used for loading and unloading of goods (mainly vegetable seeds, minerals such as kaolin and coal) and road traffic of light and heavy trucks. Annual statistics of embarkment and disembarkment at the Ancona Port are shown in Table 1. The strengths and weakness related to the harbour activities together with the economical opportunities characterise the threats and must be evaluated with a view to the sustainability of the entire port system.

Table 1: Annual statistics of embarkment and disembarkment for the years 2005–06 (tons x 10^3).

	2005		2006	
Goods	Embark	Disembark	Embark	Disembark
Petrol	1177	3688	907	3844
Coal	-	394	5	480
Cereals	10	210	23	265
Kaolin	4	287	3	264
Iron&Steel	36	33	45	25
Total	2692	6517	2542	6689
TEU	42	44	48	49
TIR+TRAILER	104	93	102	94
Passengers	500	1000	600	1000



(a) (b)

Figure 1: (a) Map of Ancona town (Italy) and (b) layout of its harbour with the sampling locations S1 and S2.

3 Meteorological data

In the present study, hourly and 4-hourly (00:00–06:00, 06:00, 0600–12:00, 12:00–18:00, 18:00–00:00) meteorological data of wind speed, wind direction, for the year 2005–2006, has been used. Table 2 gives the meteorological data for January 2005 through to December 2006. Fig. 2 reflects the statistics of hourly wind speed within the 16 sectors of provenience and for the selected time interval. It is possible to observe low winds especially in the summer season and at night time.

4 Monitoring locations

In the urban area, the municipality continuously monitors NO_x and particulate matter (PM10, PM2.5) levels. The monitoring network contains four permanent stations. Fig. 1 shows two locations of these stations in the harbour and in the city (S1, S2). Simultaneous weather and gaseous pollutants data (including SO_2, CO, NO and NO_2) were also available for data analyses. A monitoring campaign was performed between January 2005 and December 2006 in these two sites characterised by a different exposure to urban (S2) and harbour (S1) sources. A third monitoring station (S3) was located at a rural site far from the industrial and traffic emissions.

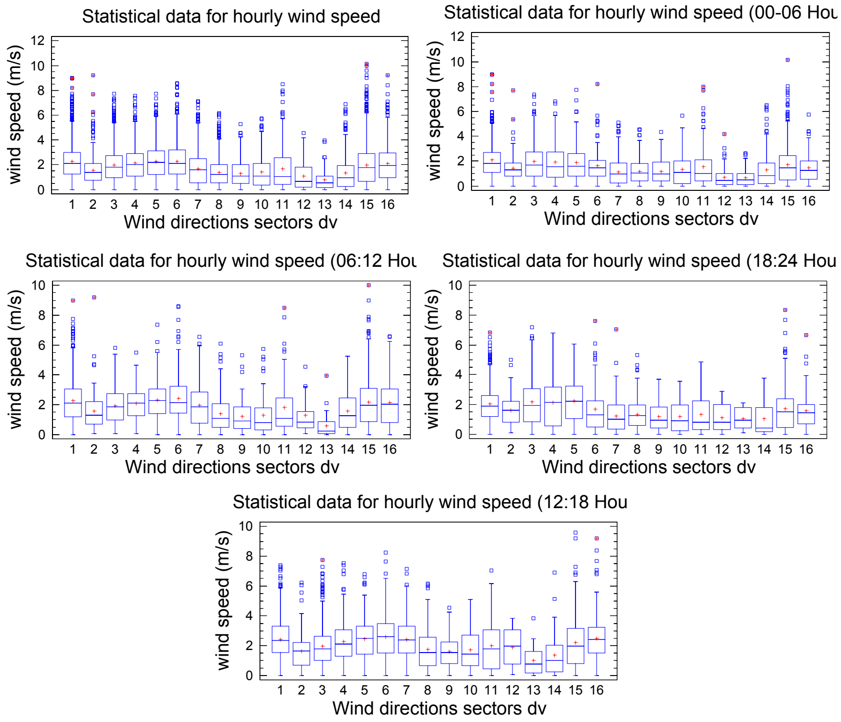


Figure 2: Statistical data for wind speed within the provenience sector and hourly segment (sector equals 22.5°).

A short description of the S1 site and of its exposure to the traffic emissions, dock activity and the duration of the period when the campaigns took place are reported in Table 1.

5 Results and discussion

The concentrations of NO_x, PM10 and PM2.5 caused by the ships, road traffic ad the local industrial activity at the S1 site were analysed and are reported in Fig. 3. At the S1 location PM10 has shown a downward trend since 1998, with a 40% decrease in the year 2006 compared to the year 1998. Within the two years of interest the data shown in Fig. 3 proves that the PM2.5 and to a minor degree also NO_2, decreased significantly in summer compared to winter, whereas the same trend is not observed looking at the coarser PM10 particulates. The distributions of the hourly time series of NO_2, PM10 and Pm2.5 at the stations S1 and S2 also deserve some attention.

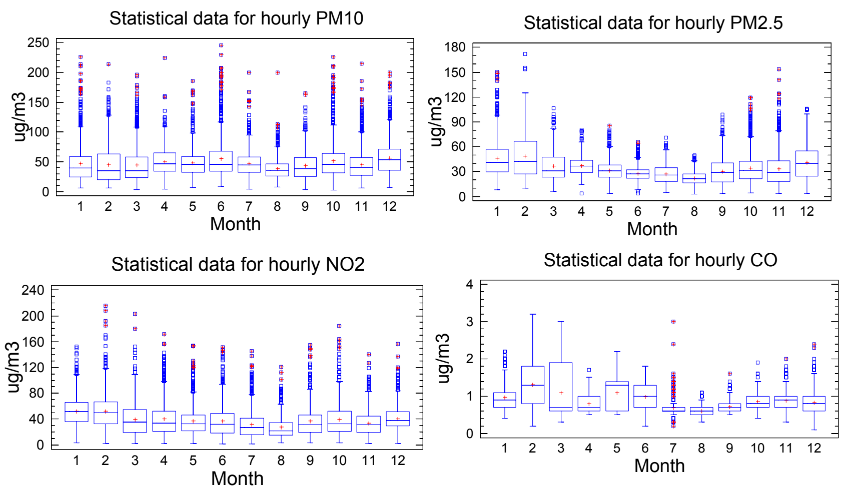


Figure 3: Statistics for PM10, PM2.5, NO_2.

Two theoretical distributions, namely lognormal and Weibull, were used to fit the measured PM10. PM2.5 and NO_2 data. The equations of these distributions were found and the distributional parameters estimated by the method of maximum-likelihood for the theoretical distributions (Georgopoulos and Seinfeld [2]; Lu [5]). Overall the Weibull distribution was found to be the most appropriate to represent all the parent distributions and used to fit the entire measured data. Fig. 4 shows the shape and scale factors for PM10. PM2.5 and NO_2 for the locations S1, S2, S3. The standard deviations of the annually averaged parameters can be considered moderate but require evaluation. We have used the atmospheric Turbulence and Diffusion Laboratory (ATDL) model already adopted to predict long term average pollution concentrations for a variety of urban situations (Gifford and Hanna [8]).

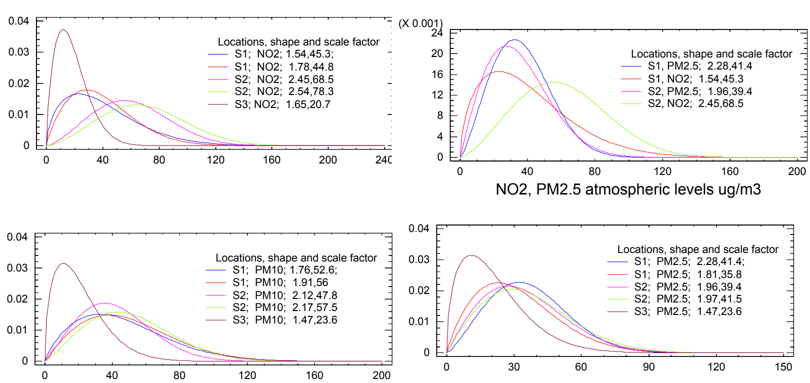


Figure 4: Weibull shape and scale factor for PM10, PM2.5 and NO_2.

In its simplest form the ATDL model assumes the following simple relationship between air pollution concentration χ and wind speed u

$$\chi=C*Q/u \tag{1}$$

where Q is the average source strength and C is an atmospheric stability factor given by $C=\left(\sqrt{\frac{2}{\pi}}*x^{1-b}\right)*\left(a*\left(1-b\right)\right)^{-1}$ and x is the distance from a receptor point to the upwind edge of an urban pollution source. The constants a and b are defined by the vertical diffusion length , σz=axb. Daly and Steele (1975) used a modified version with χ=K/u where K=C*Q. Bencala and Seinfeld also made the important point that if χ and u are related as shown than the air pollution data are lognormally distributed if wind speed data are lognormally distributed. Simpson et al. (1983) have also shown that irrespective of the statistical distributions of air pollution data and wind speed the cumulative frequency distributions F(χ) and G(u) of air pollution and wind speed are related, then it would appear that if χ=K/u is applicable to all the data, the K value can be calculated from F(χ) =1- G(u) where F(χ)=prob(X≥ χ) anf G(u)=prob(U≥u). This in essence implies that the χ value corresponding to the p-percentile χp in F(χ) and the u value corresponding to the (100-p) percentile u100-p are related by K= χp* u100-p (equation (1)).

Looking to the relationship between the wind speed and air pollution levels we considered the data as hourly average, six hours average and data collected at the same hour of each day, the hours chosen being 06:00, 13:00 and 20.00 which should roughly correspond to stable, instable and neutral conditions respectively, even if the sea breeze effects make the general characterisation of atmospheric stability really difficult. The pollutant and wind speed cumulative distributions using the p-percentiles 30, 35, 40, 45, 50, 55, 60, 65, 70 have been used to see how well equation (1) applies by fitting a regression model of the form y=b*x where y = χp and x=1/(u100-p)n. The relationships come out to be best represented by an exponential relation of the type C(ug/m^3)=K*un. The K and n values are reported in table 2.

It would appear from Table 2 that the relationship suggested by equation (1) as a representation of the relationship between non extreme percentile values of wind speed and pollutant concentrations may be widely applicable but with a wind exponent varying from 0.5 to 1 depending upon the locations S1, S2, S3. The percentiles of the wind speed in the cumulative frequency distribution refer to a mix of atmospheric stabilities and the wind exponent n could refer to distinguishing and specific local dispersion conditions.

For estimating the assimilative capacity of the atmosphere, a different approach based on a dispersive ventilation coefficient (VC) was tried. VC is computed by the product of mixing height and the average wind speed for the two seasons, winter and summer. The Atmospheric Environment Services, Canada, has classified that high pollution potential occurs when the afternoon ventilation coefficient is less than 6000 m2s-1 and mean wind speed does not exceed 4ms-1, and during morning hours, the mixing height is less than 500m and mean wind speed does not exceed 4ms-1 (Stack Pole [12]; Gross [13]).

Table 2: K and n values for S1, S2 and S3 site locations.

Site Location S1						Site Location S2						Site Location S3					
PM_{10}		$PM_{2.5}$		NO_2		PM_{10}		$PM_{2.5}$		NO_2		PM_{10}		$PM_{2.5}$		NO_2	
K	n	K	n	K	n	K	n	K	n	K	n	K	n	K	n	K	n
60	0.70	41	0.63	50	0.74	55	0.5	44	0.63	80	0.51	35	0.84	26	0.83	-	-
Site Location S1																	
Hour 06.00						Hour 13.00						Hour 20.00					
PM_{10}		$PM_{2.5}$		NO_2		PM_{10}		$PM_{2.5}$		NO_2		PM_{10}		$PM_{2.5}$		NO_2	
K	n	K	n	K	n	K	n	K	n	K	n	K	n	K	n	K	n
37	0.6	30	0.57	31	0.67	111	0.86	67	0.87	85	0.93	49	0.65	34	0.56	43	0.80

Thus, the ventilation coefficient, boundary layer height for winter (December) and summer (July) at Ancona are shown in Fig. 5, which reveal that morning and evening mixing/inversion height values in both months are low compared to day time values.

The diurnal variation of mixing height follows a similar trend in both these months, since the wind speed is higher in the daytime during the summer season compared to morning and night time. Due to low wind speed and mixing height, the ventilation coefficient is lower in winter compared to the summer season. The maximum value of the ventilation coefficient is recorded as about 2300 m^2s^{-1} in the month of July and 1200 m^2s^{-1} in the month of December, which indicates that no season satisfies the Atmospheric Environment Services criteria. On this basis of this criteria it can be observed that no safe emission hours can be advised throughout the year, even if this approach is not sufficient to draw a conclusion because it does not include sources of pollutants.

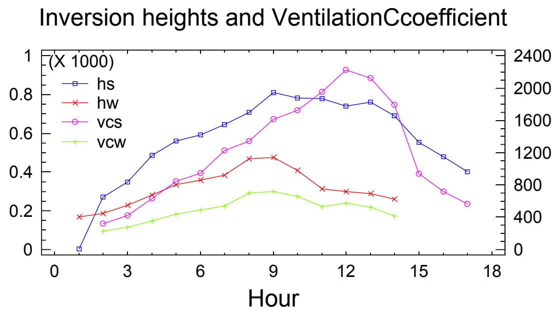


Figure 5: Boundary layer height and ventilation coefficient in winter and summer.

6 Conclusions

The model χ=C*Q/u as a representation of the relationship between the opposing percentile-values in the statistical distribution for the 30 to 70 percentile requires an exponent to wind speed ranging from 0.3 to 1. The agreement was good for PM10, PM2.5 or NO_2 on an hourly basis or daily or for any specific hour of the day. The empirical derived C-factor (K(=C*Q)) in the ATDL model is due to the detailed temporal relationship between χ and u and therefore not to the atmospheric stability, which seems more related to the wind speed exponent n.

Assimilative capacity within the harbour area, determined based on a ventilation coefficient, reveals that the VC is always less than 2400 m^{-2} s^{-1}, which indicates that the studied area has high pollution potential implying that assimilative capacity is low. An assessment of this approach would enable one to draw some plausible operational schedule for the sources. The results also reveal that the assimilative capacity is better in the summer season than in winter. In the present study the influence of topographical features and other complex terrain related forcings have not been considered.

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