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Meteorological effects on PM10 concentrations in an urban industrial site: a statistical analysis

Francesca Fedele[1,2*], Micaela Menegotto[1], Livia Trizio[1], Lorenzo Angiuli[1], Anna Guarnieri Calò Carducci[1], Roberto Bellotti[2,3], Roberto Giua[1], Giorgio Assennato[1]

[1]*Apulia Region Environmental Protection Agency (ARPA Puglia), Corso Trieste 27, 70126 Bari, Italy*

[2]*Università degli Studi di Bari, 70126 Bari, Italy*

[3]*Istituto Nazionale di Fisica Nucleare Sezione di Bari, 70126 Bari, Italy*

Abstract

This study deals with the analysis of 8 years time series of PM10 and meteorological data collected in the city of Taranto – Italy, which is characterized by the proximity to a large industrial area which includes the largest European integrated steel plant, an oil refinery and a cement plant. In particular we focus on a small neighbourhood called Tamburi characterized by several exceedances of regulatory limits with respect to PM10. This neighbourhood is located less than 1 Km away from the steel plant mineral stockyard, downwind at wind direction from North-West quadrant. The aim of the study is to identify specific wind conditions leading to deterioration of air quality with respect to PM10 concentrations. We chose two sampling sites of PM10 from ARPA Puglia Air Quality Monitoring Network, one located in Tamburi and the other in a Taranto neighbourhood called Talsano, similar to the first in population density and urban morphology but much farther from the mineral stockyard. Meteorological data are obtained from a station located in Taranto from the same Air Quality Monitoring Network. To identify the specific wind conditions, we looked for critical wind speed thresholds and wind speed permanence in terms of consecutive hours over the threshold. Combining thresholds and permanence we defined some meteorological criteria and applying them we divided into two classes every day of the observation period naming them "Wind Day" and "No Wind Day". According to this classification we performed a statistical analysis (Wilks, 2006) on the two PM10 data sets; we also performed a statistical hypothesis testing building two different distributions, one obtained from PM10 concentration and the other from the difference between the PM10 concentrations in two sites, and for each meteorological criterion we build a ROC curve. Days of Saharian advection, identified using a canonic method (EC, 2011), were eliminated from the dataset. The study shows that Talsano site exhibits a constant behaviour, that is a decrease of PM10 concentrations in the days classified as "Wind Day" with respect to the "No Wind Day" class, due to

*Corresponding Author: f.fedele@arpa.puglia.it

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dilution effect of strong winds. Tamburi site shows an opposite behavior. This anomaly is due to the extreme proximity of emission source. Furthermore we found that the value of the area under the ROC curves obtained for each meteorological criterion is in the range 0.69 – 0.89 meaning that all classifiers give a sufficiently good separation.

Keywords: Metheorological effects on air quality; industrial emission impact on PM10 concentration.

1. Introduction

This study deals with the analysis of 8 years l time series of PM10 and meteorological data (2005-2012) from ARPA Puglia Air Quality Monitoring Network collected in the city of Taranto – Italy which is characterized by the proximity to a large industrial area including the largest European integrated steel plant, an oil refinery and a cement plant.

In the present work we focus our attention on a small Taranto neighbourhood called Tamburi characterized by several exceedances of regulatory limits with respect to PM10 and located 1 Km away from the steel plant mineral stockyard, downwind at wind direction from North-West quadrant.

The aim of the work is to study the relation between PM10 concentrations collected in Tamburi and Talsano - another Taranto neighbourhood similar to the first in population density and urban morphology but much farther from the mineral stockyard - and meteo data in order to identify specific wind conditions leading to deterioration of air quality. In particular we want to show how the proximity to the industrial area affects this relation.

We study the time interval 2005-2012.

2. Procedures

Meteo data are from a station belonging to ARPA Puglia Air Quality Monitoring Network. A validation procedure, based on the intercomparison with neighboring stations, has been performed on the dataset. An interpolation procedure has been performed in case of days with missing data up to 3 hours consecutive missing data; days with more than 3 hour missing data have been removed from the dataset.

PM10 data are from ARPA Puglia air quality stations located in the two area of interest, Tamburi and Talsano. Missing data have been replaced with data from other stations sited nearby each site and similar in terms of average patterns.

A previous study, covering just one year and performed in ARPA Puglia, showed that meteo conditions characterized by intense winds from North-West quadrant and lack of precipitations lead to a deterioration of air quality in terms of PM10 concentrations in Tamburi area. Wind direction from North-West quadrant is, as already specified, that for which Tamburi results downwind to the mineral stockyard and to most of the production plants.

Being interested in the relation between wind conditions and PM10 concentrations, we first performed an *a priori* separation, according to meteo features, of days which hypothetically support an increase of PM10 concentrations (named "Wind Days" -WD) from days which do not support this increase (name "no Wind Days" - nWD).

More in detail we considered as changing features wind speed and its persistence; wind direction has remained fixed ($270° \leq$ direction $\leq 360°$) being a site-specific factor, that is,

WD will always be characterized by North-West wind directions while nWD by winds from the remaining three quadrants.

In order to separate WD from nWD 16 meteorological criteria (table 1) were tested: days characterized by wind speed greater than a given threshold (0 ÷ 9 m/s) for a time at least equal to the required persistence were classified as WD; all the remaining days were classified as nWD. For all criteria it is required the additional condition of lack of precipitations

Table 1. "Wind Days" identification criteria.

Wind speed threshold (m/s)	**0**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Persistence (number of hours)	IDENTIFICATION CODE							
3		**3**-*3*	**4**-*3*	**5**-*3*	**6**-*3*	**7**-*3*	**8**-*3*	**9**-*3*
4	**0**-*4*	**3**-*4*	**4**-*4*	**5**-*4*	**6**-*4*	**7**-*4*	**8**-*4*	**9**-*4*
6	**0**-*6*							

In order to make the result of the analysis dependent only on anthropogenic emissions, days characterized by saharian dust advection, identified using a canonic method [2], were eliminated from our dataset or processed separately. During these days, very high values of PM10 concentrations, which should be considered of natural origin, are recorded on a large area (regional scale).

Further in detail, saharian days were deleted from nWD list obtained for each one of the 16 criteria and those saharian days which overlap with days classified as WD were considered as WD and deleted from the saharian days list.

For each criterion we got a set of WD and one of nWD and we made a statistical analysis [1] of the corresponding distributions of PM10 concentration.

3. Results

For each criteria, that is for each WD/nWD separation, we build PM10 concentration distributions for Tamburi and Talsano datasets.

Being interested in a synthetic and explanatory presentation of the distributions, we choose to represent, for each criteria, four boxplots (WD Tamburi, nWD Tamburi, WD Talsano, nWD Talsano). The results of this representation for 2 of the 16 criteria studied is reported in Fig. 3. The other 14 results, here not reported, show the same trends.

For every meteo criterion, the two areas always show an opposite behavior in terms of the concentration of PM10: in Tamburi data there is a rise in the concentrations of PM10 in those days identified as WD , vice versa in Talsano data there is a decrease in the values of PM10 concentrations in the same days. Talsano response to weather conditions is in line with expectations as intense wind leads to a decrease of concentrations due to dilution and transport effect of strong winds. Tamburi area represents a singularity showing a completely opposite behaviour. This anomaly can be interpreted as a direct consequence of extreme proximity to the emission source. In this context Talsano station can be seen as a background site meaning that by subtracting the PM10 value measured by Talsano station from that of Tamburi station, it is possible to get a likely estimate of the impact due only to the closest emitting source.

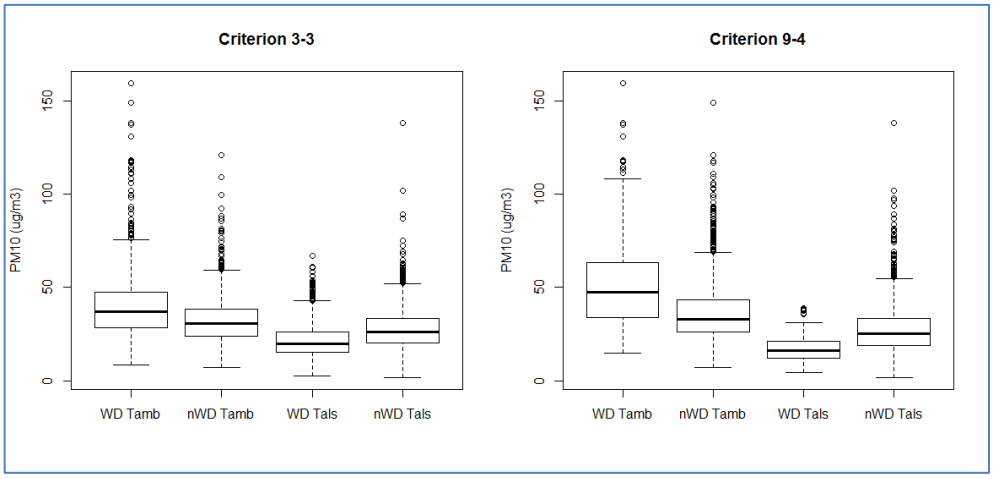

Fig.1. Boxplots of PM10 concentration distributions obtained from 2 different criteria: 3-3 and 9-4.

Criterion named 9-4 best stresses this difference of behaviour and this result is in line with the interpretation just suggested as very strong winds (≥9 m/s), remaining for at least four consecutive hours, cause a very intense transport and fall-out of dust on Tamburi area.

In Fig. 2 we represent the median values for each PM10 distribution as a function of wind speed threshold for all criteria with 3 hours persistence plus the 0m/s criteria. The 4 hours persistence criteria, not shown in the figure, don't exhibit significantly different trends with respect to the 3 hours criteria.

Focusing our attention on days classified as WD (red crosses for Tamburi, yellow squares for Talsano), there is a remarkable growth with of the medians relative to the distributions recorded at Tamburi station as a function of wind speed threshold. Talsano exhibits an opposite trend.

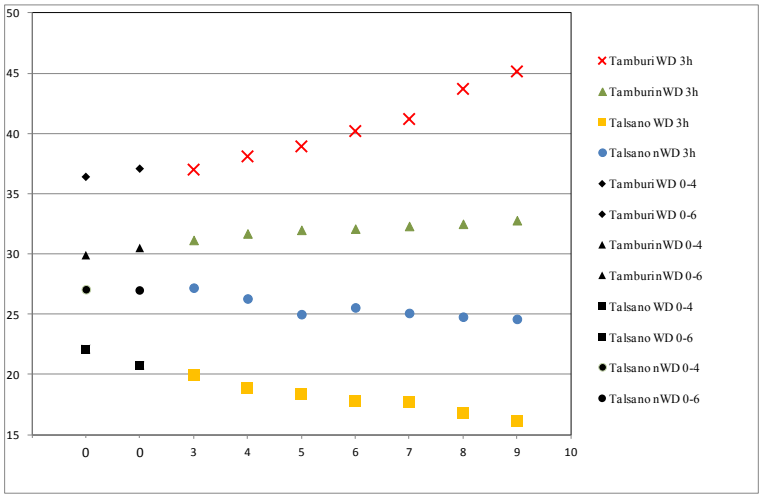

Fig. 2. Median values of each PM10 distribution as a function of wind speed threshold.

Concerning nWD, concentration median values at Tamburi (green triangles) are higher than Talsano ones (blue circles) for all criteria, due to dust resuspension phenomena which are independent from wind direction.

Moving our attention to 0m/s criteria, for Talsano PM10 distribution median values it is expected that with decreasing wind speed threshold the two curves of WD and nWD medians should approach up to touch each other for speed threshold equal to 0m/s. This does not occur as it is evident in Fig. 2. The reason lies in local wind circulation, characterized by strongest winds predominantly from North-West quadrant (characteristic of WD) as shown by wind roses in Fig. 4, with consequent major dilution effect.

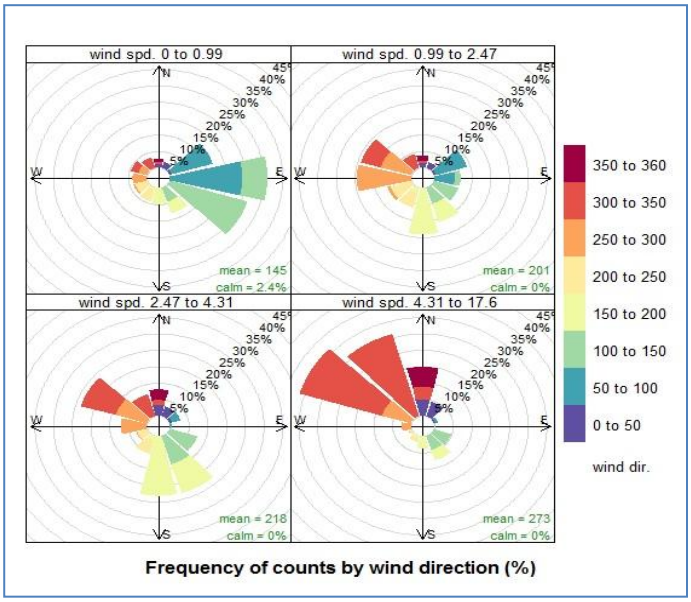

Fig. 3. Wind rose diagrams separated by wind speed intervals (2005-2012).

To make the analysis more complete, we selected two of the 16 criteria (7-4 and 9-4) and built a hypothesis test for PM10 concentration distributions in order to verify two null hypotheses:

- during WD, PM10 concentrations exceed a given threshold value;
- during WD, the difference in PM10 concentrations recorded in the two areas is higher than a given threshold value.

We choose the 9-4 criterion because wind speed threshold equal to 9m/s seems to best highlight the effect of WD on PM10 concentrations.

For each test we constructed the ROC curve and considered the area under the curves as a quality parameter of the classifier. Results are shown in Fig. 4. It is evident that difference in PM10 concentrations is the parameter which best discriminate between the WD and the nWD. This value represents a good measure of emissions from sources close to Tamburi and the result confirms that the effect of the WD on Tamburi station is due to the extreme proximity of the emissive source.

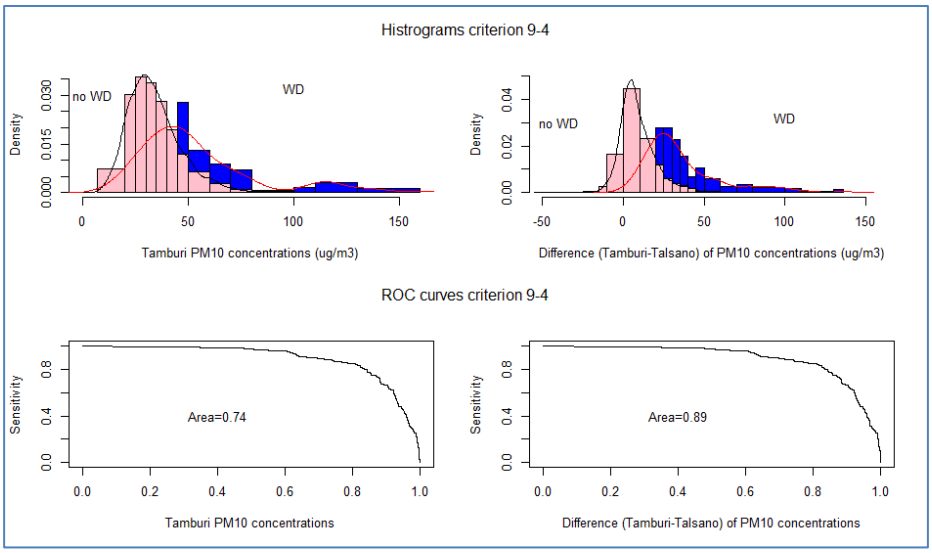

Fig. 4. Histograms and ROC curves for criterion 9-4.

4. Conclusions

From the results it can be deduced that the site of Talsano shows a behavior in line with expectations in the sense that there is a decrease in the concentration of PM10 in the days classified as WD compared to the days classified as nWD due to the natural dilution effect of strong winds. Tamburi site exhibits an opposite behaviour and is always characterized by high PM10 concentrations with respect to Talsano site. This effect, due to the extreme proximity of emission source, is strengthened by "Wind Days" conditions.

A further verification of this result comes from having found that the difference in PM10 concentration recorded in the two areas is the parameter that best discriminate between WD and nWD as confirmed by the values of the areas under the ROC curves.

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