Development of pollution indexes for measuring air quality in urban areas

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ABSTRACT

Two different pollution indexes have been developed and implemented at the urban area of Naples (Italy). Data collected during 2003 from nine monitoring stations are analysed. The first index aims at measuring the status of air pollution with respect to its effect on human health. Breakpoint concentrations have been defined assuming limit values established by European Community and international associations like World Health Organisation. The second index aims at showing clearly the occurrence of exceedences of limit values established by EC directives.

INTRODUCTION

The need for public authorities of powerful but simple tools for managing information about air quality and for communication to population requires the development of pollution or air quality indexes. Moreover, the broad use of air monitoring networks in urban and industrial areas makes available a large amount of air quality data. For this reason in the last years different pollution indexes have been proposed. Air quality indexes can have different goals: i) measuring air quality with respect to human health effects; ii) checking the exceedences of limit values; iii) analysing the relationship of pollutant level with other parameters such as: meteorological conditions or vehicular emissions.

The main objective of air quality indexes is measuring the air quality with respect to its effects on the human health. Typically this is a daily quality index (e.g.; AQI proposed by EPA [1]). Other indexes of the same kind were proposed by several authors [2-5]. The second objective is the clear representation of limit value exceedences. In this case few papers are reported in the literature [4].

In this paper the procedures for the evaluation of two different pollution indexes are reported. The first one measures the air quality with respect to its effect on human health and can be seen as a modified version of AQI defined by EPA. It will be indicated as pollution index (PI). The second one aims at giving a clear representation of the exceedences of limit values established with EC directives [6-8] and will be named as exceedence's index (EI)

DEFINITION AND APPLICATION OF THE POLLUTION INDEXES

Pollution index (*PI*) Air quality in the city of Naples is monitored at nine fixed stations measuring conventional pollutants: CO, NO_2, NMHC, SO_2, PM_{10}, O_3 and SO_2 [9]. The stations can be classified as: a background station (NA1), two air quality in residential area stations (NA2

and NA3), four high traffic area monitoring stations (NA4-NA7) and two photochemical pollution monitoring stations (NA8 and NA9).

A more detailed description of the criteria for the development of the pollution index *PI* is reported in [10]. Briefly the following pollution categories have been defined:

- *Good quality*: the concentration of the pollutant is below the target or guide value established for the protection of the environment by EC;
- *Low pollution*: the concentration is below the limit value established by EC for human health protection;
- *Moderate pollution*: the concentration is above the limit value established by EC;
- *Unhealthy for sensitive groups*: the concentration of the pollutant can give effect on sensitive groups (children, asthmatics, ...);
- *Unhealthy*: the concentration of the pollutant can have effects on all the population and/or higher effects on sensitive groups.

With respect to EPA AQI five categories instead of six have been defined, and two instead of one pollution categories lower than "moderate" are present. As a consequence, also breakpoint concentrations are somewhat different. The reference scale of the pollution index (*PI*) here proposed, with the corresponding pollution categories and breakpoint concentrations, is reported for each pollutant in Table 1. The pollution index can assume values in the range 0-100. As an example, in the case of PM10 if concentration is in the range 50-143 μg/Nm^3 then pollution category is "moderate pollution" and PI index is in the range 50-69.

Pollution category	**PI**	**PM_{10} 24 h**	**NO_2 1 h**	**CO 8 h**	**SO_2 24 h**	**O_3 1 h**	**O_3 8 h**
----------	100	500	1900	30	1000	600	500
Unhealthy							
----------	85	238	950	15.5	500	324	223
Unhealthy for sensitive groups							
----------	70	144	400	11.6	250	240	180
Moderate pollution							
----------	50	50	200	10	125	180	120
Low pollution							
----------	25	20	40	4	20	-	65
Good quality							

Table 1 – Pollution index proposed (volumes are standardised at T=293 °K and P=101.3 kPa). Concentrations are in μg/Nm^3 apart from CO in mg/Nm^3

The evaluation of the *PI* of pollutant *i* at station *j* (PI_{ij}) is carried out by a linear interpolation among the reference scale values reported in Table 1:

$$PI_{ij} = \left[\frac{PI_{hi} - PI_{lo}}{BP_{hi} - BP_{lo}} (Y - BP_{lo}) + PI_{lo} \right]_{ij} \quad (1)$$

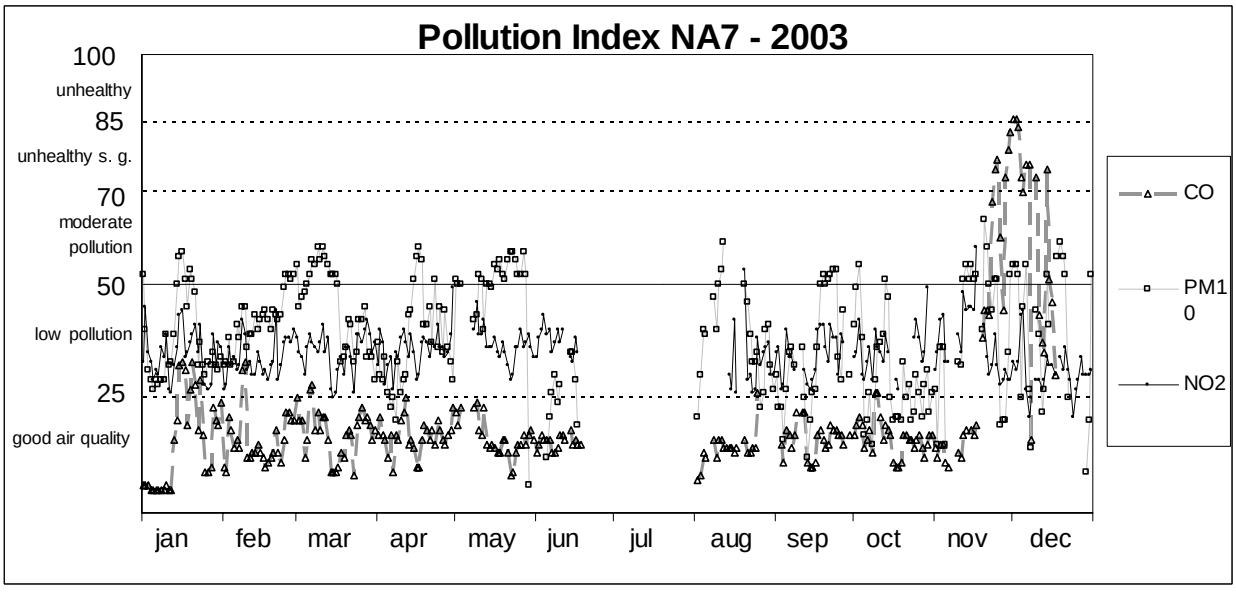
where : Y = the daily reference concentration; BP_{hi} = the lowest breakpoint concentration that is greater than or equal to Y; BP_{lo} = the highest breakpoint concentration that is less than or equal to Y; PI_{hi} = the PI value corresponding to BP_{hi}; PI_{lo} = the PI value corresponding to BP_{lo}.

The daily reference concentration Y corresponds to the maximum value of hourly (NO_2, SO_2, O_3) or 8-hour (CO and O_3) average concentration or simply the 24 hours average concentration (PM_{10}). If a concentration level higher than that reported in Table 1 in correspondence of PI equal to 100, is measured, the maximum value of the PI is assumed (PI=100). To make clear the communication of the air quality to population the use of symbols is proposed (Table 2).

Pollution category	Symbol
Unhealthy	
Unhealthy for sensitive groups	
Moderate pollution	
Low pollution	
Good quality	

Table 2 – Symbols proposed for a better communication to population.

As an example pattern of pollution index obtained for NA7 is reported in Fig. 1.



It is important to remember that breakpoint concentrations of *PI* proposed in this paper have been established for single pollutants. Pollutants, when in mixture, can have additive or synergistic effects on human health. At the present the knowledge of these interactions among air pollutants is still rudimentary. Evaluation of *PI* assuming additive effects of the different pollutants is reported [10] with respect to data collected during 2001-2002. A significant increase in the values of *PI* was obtained [10] when additive effects have been considered.

Exceedence's Index (*EI*) A clear representation of the occurrence of the exceedences of limit values (*LV*) established by EC has been obtained assuming the following procedure. For each pollutant *i* and each station *j* the value of the daily reference concentration is normalized with respect to the corresponding limit value:

$$\bar{Y}_{ij} = \frac{Y_{ij}}{LV_j} \cdot 100 \tag{2}$$

Then the *EI* for station *j* was evaluated as:

$$EI_j = \sum_{i=1}^{5} \chi_{[\bar{Y}_{ij}=0]}(\bar{Y}_{ij}) + 10\sum_{i=1}^{5} \chi_{[0<\bar{Y}_{ij}<50]}(\bar{Y}_{ij}) + 10^2 \sum_{i=1}^{5} \chi_{[50\le\bar{Y}_{ij}<100]}(\bar{Y}_{ij}) + 10^3 \sum_{i=1}^{5} \chi_{[\bar{Y}_{ij}\ge100]}(\bar{Y}_{ij}) \tag{3}$$

Since the pollutants considered are five the EI_j index assumes the following values: EI_j=0 if there are not valid data; $0<EI_j\le50$ if the value of daily reference concentration is always less than $0.5LV$; $100<EI_j<500$ if the value of daily reference concentration is always $< LV$; and $EI_j \ge 1000$ if the value of daily reference concentration is at least in one case $\ge LV$.

As an example the patterns of *EI* index of NA1 and NA5 stations for 2003 are reported in Fig. 2.

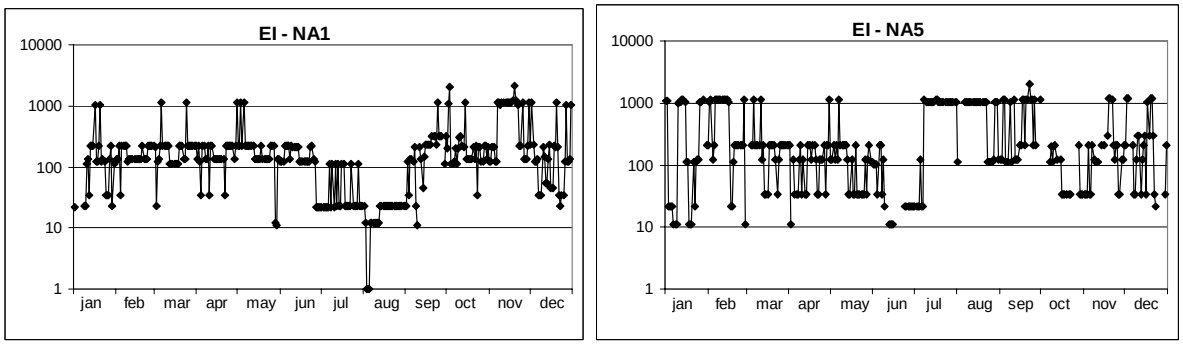


Figure 2 – Exceedence's Index of stations NA1 (background level station) and NA5 (high traffic station).

The *EI* index has also been evaluated for each pollutant *i* over the whole urban area (UEI_i). In this case the equation to evaluate the *UEI* index is:

$$UEI_{iu} = \sum_{j=1}^{n} \chi_{[\bar{Y}_{ij}\ge0]}(\bar{Y}_{ij}) + 10\sum_{j=1}^{n} \chi_{[0<\bar{Y}_{ij}<50]}(\bar{Y}_{ij}) + 10^2 \sum_{j=1}^{n} \chi_{[50\le\bar{Y}_{ij}<100]}(\bar{Y}_{ij}) + 10^3 \sum_{j=1}^{n} \chi_{[\bar{Y}_{ij}\ge100]}(\bar{Y}_{ij}) \tag{4}$$

where *n* is the number of air monitoring stations.

In Fig. 3 the pattern of UEI for each pollutant is reported.

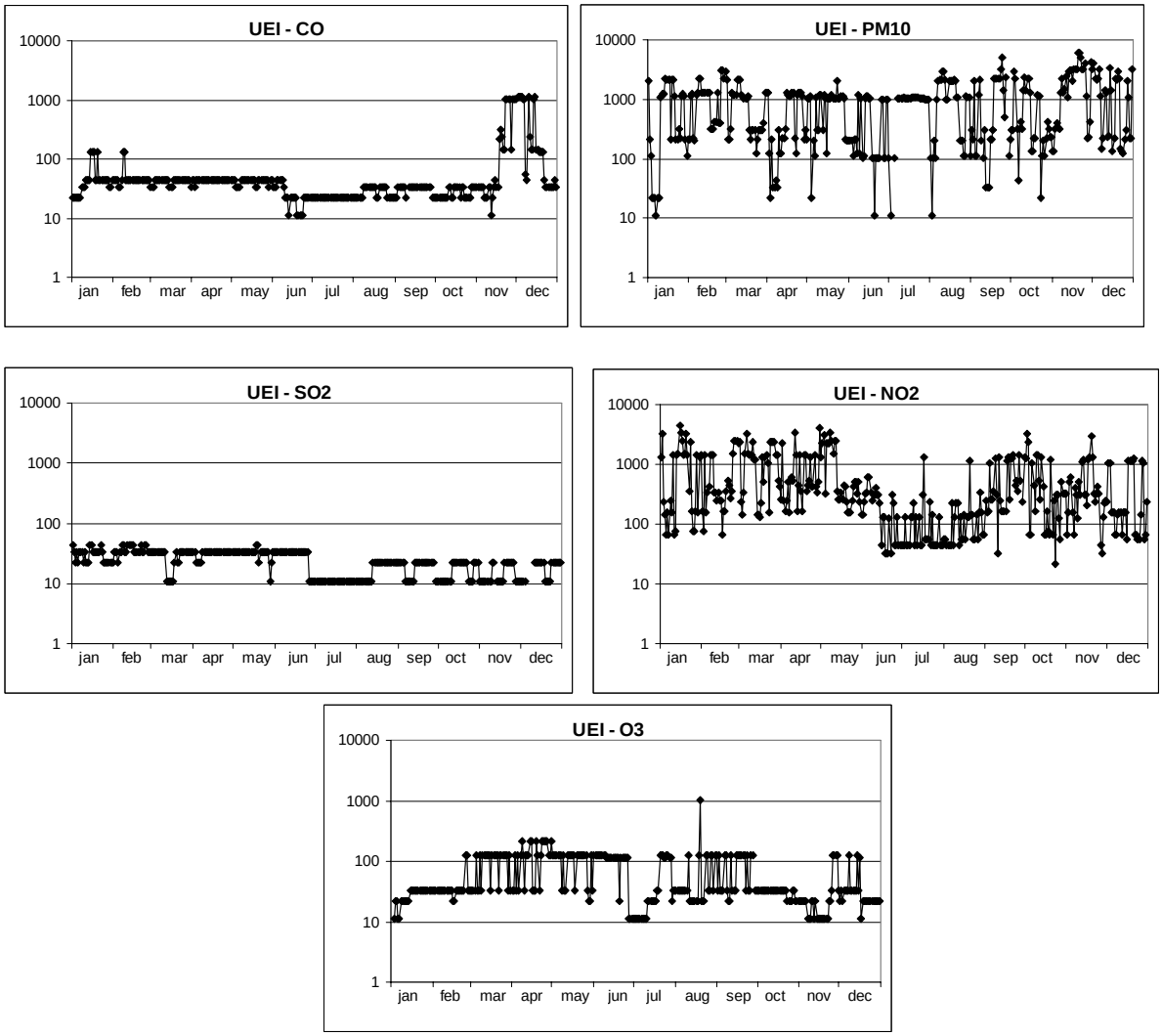


Figure 3 – Exceedence's Index on the urban area (*UEI*).

It is evident how both figures 2 and 3 show clearly the occurrence and number of exceedings of limit values.

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