# DEFINITION OF NOVEL HEALTH AND AIR POLLUTION INDEX BASED ON SHORT TERM EXPOSURE AND AIR CONCENTRATION LEVELS

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**Abstract:** Health impact assessment has become important in the development of air quality policies and in finding the relationships between pollutants concentration and health effects. In our work we presented a novel index able to evaluate the effects on the human exposure caused by ambient air pollution in urban areas. The index is able to link both health risk factors and pollutants levels. The indexe~~s~~ is of additive type and is composed by two terms: the former is based on pollutants concentration and is connected with EPA air quality index (AQI), while the latter is composed by an adimensional term based on the exposure levels. We tested the methodology using PM10 as studied pollutants. The spatial and temporal variation of its health impact was evaluated by means of index maps applying the above methodology in the city of Rome during three selected episodes. Our study shows index maps for all episodes linked to population and to pollutants.

***Key words:*** *Air dispersion model, Exposure, Health effects*

## 1. INTRODUCTION

Quantitative health impact assessment has become increasingly important in the development of air quality policies. Two modes or methods of study are generally relied on to quantify the relationships between pollutants and specific health effects: epidemiological and toxicological approaches. Such methods have limitations and they are based on quantifying the level of adverse effects in a given human population as results of exposure. Toxicological studies often do not represent the complex mix of pollutants in the atmosphere. Epidemiological studies, for example, depend on adequate community monitoring and the ability to associate a cohort with ambient data using both air quality and Relative Risk (RR) indexes.

Air quality indexes are adimensional variables that synthetically represent the general state of the atmospheric pollution. The interest towards the construction of indexes for the quality of the air has been being testified for many years of debate, beginning from the fundamental jobs of Ott and Hunt (1976), up to the most recent contributions of Trozzi et al. (1999), Khanna (2000), Murena (2004), Cheng et al. (2004) and Kyrkilis et al. (2007). The building of a synthetic index regards different phases: the definition of starting elementary indexes, the choice of the order with which to cluster them, the determination of an aggregation function (spatial, temporal and/or multi-pollutant) and of the procedures of standardization. Indexes are either related to health risk factors (link to RR based on the toxicity) or air quality. Both do not consider the actual population exposure and the anthropogenic weight on the environment produced by air pollutants. In fact an high polluted area, involving e.g. high health risk factors, could not produce the estimated health effects on unpopulated areas.

A modified version of the index AQI (Air Quality Index) developed by the EPA is presented for the determination of the effects caused by the human exposure to ambient air pollution in an urban area. For ~~the~~ exposure and health assessments two pollutants were chosen: PM10 and Ozone. In this paper we present results related to PM10. The novelty of the index is in the spatial distribution of the input data (pollutants concentration by model and population density), that allow to build a territory map of the new index "environmental - sanitary". We tested our work to evaluate the spatial and temporal variation of exposure and health impact of the urban population due to ambient air pollution in the city of Rome.

## 2. BRIEF DESCRIPTION OF THE STATE OF ART ON AIR QUALITY INDICATOR

In front of a great quantities of monitoring data hourly, related to different typologies of pollutants, both the population and the political administrator have necessity to use indexes easy to reading. Therefore it is necessary to bring back the data to a convinced and appreciable measure of the quality of the air.

A good index has to have the followings characteristic: it has to be reliable, it has to be comprehensible, to give an immediate perception of the pollution; it has to be flexible, easily to update; it has to be diffused, adopted that is by the most greater number of Countries. The pollutants more used in the definition of the air quality indexes are: $PM_{10}$, $PM_{2.5}$, CO, $NO_2$, $O_3$, $SO_2$. This choice is born from the fact that the indexes are formulated to give indications to the population to keep away from the acute effects (type cardiovascular and respiratory). To be able to put together different pollutants, is necessary to pass from the concentrations unity to an adimensional scale, assuming for all the pollutants the similar range of values. The definition of the earliest air pollutants standards born to the second half the sixties by the work of the American agency US-EPA (United States Environmental Protection Agency). One of the first synthetic indexes, shortly time adopted by US-EPA, it was the PSI (Pollution Standard Index) elaborated by Ott and Hunt [1]. In 1999 the EPA replaces the index PSI with the AQI (Air Quality Index) that it incorporates two new standards, those for the ozone ground level and for the fine dusts. The PSI index calculates for every monitoring station the hourly maximum concentration for the $NO_2$, the $O_3$ and the $SO_2$ and the daily middle concentration for the PM10 and PM2,5. Trozzi et al. (1999) have introduced an air quality index to assess the quality of the air in the area of Trento. The target was that to produce an index able to synthesize the different effects of pollutants in atmosphere. Khanna (2000) has developed an index based on health's loss caused by the exposure to the atmospheric pollution (API). The adopted methodology is turned to an improvement of the PSI. Bruno and Coaches (2000) has underlined as the order with which are collected data pollutants, the spatial and temporal aggregation, can influence the final result. Cheng (2004) have proposed a new index RAQI, that combines the PSI with a function entropy. Murena (2004) has developed an index of daily pollution index for the Naples site. Such index is a version modified of the AQI developed by the EPA and keeps in mind of the limits of quality of the air in Europe. In the same work, the index UPI has been proposed, which calculates a spatial aggregation of the data of the single monitoring stations with weight average and it keeps in mind of the additive effect more pollutants. Kyrkilis et all. (2007) have developed an AQI admitted based on the effect combined of 5 pollutants (CO, $SO_2$, $NO_2$, $O_3$ and PM10), calculated considered the limit of quality of the air European.

## 3. METHODOLOGY

The aim of this study is to evaluate as alternative indexes, using both dispersion model results and maps of population, connected to the "health-environmental" risk. For such aim, it is necessary to define the "health-environmental" risk within the environmental ones. With the expression "environmental risk" we mean all the possible damages to the natural and anthropogenic components of the environment system, that directly or indirectly have an effect on the human health. The more used definition of environmental risk is that derived by a proposal by the United Nation Disaster Relief Coordinator (UNDRO), according to which the risk can be interpreted as resultant of the stress that interests a given territory (dangerousness), of the quantity and of the type of the exposure elements and of the predisposition against such elements (vulnerability).

The novelty of the proposed index is to combine, for a large urban area, the three variables dangerousness (pollutant concentration), vulnerability (Relative Risk or toxicity) and exposure (exposed people and environment), so that it accounts for any components related with the effects of the atmospheric pollution on the human health, as in the classical approach of the epidemiology, and the anthropogenic pressure on the environment.

### The "health - environmental" index

The new index proposed **takes into account** two factors: the concentration of the PM10 pollutants and the population density. The first term considers the pressure of the atmospheric pollution on the environment and is strictly connected to the air quality index in its classical formulation, for a single pollutant:

$$I_{AQI} = \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}}(C_{inq} - BP_{LO}) + I_{LO} \tag{1}$$

The partition in classes of air quality is based on the European standards ones (more restricted in comparison to the standards of the EPA).

The second term takes into account the population exposed to air pollution, through an adimensional variable type, obtained divided the population density of a given area for the overall maximum density over the studied one. Such variable is multiplied for a factor 100, to make it of the same order of the first term (1), and then it is elevated to a coefficient *1/β*:

$$I_{pop} = \left(\frac{POP}{POP_{\max}} \cdot 100\right)^{\frac{1}{\beta}} \tag{2}$$

The coefficient *1/β* should be a function of the tossicity/risk of the pollutant to which the population is exposed, although in this study it was selected to balance the contribution of two additional terms. The proposed "health-environmental" index is determined therefore from the following formulation:

$$I_{AQI-Pop} = I_{AQI} + I_{pop} = \frac{I_{HI} - I_{LO}}{BP_{HI} - BP_{LO}}(C_{inq} - BP_{LO}) + I_{LO} + \left(\frac{POP}{POP_{\max}} \cdot 100\right)^{\frac{1}{\beta}} \tag{3}$$

The above formulation considers both the contribution of the local air quality and the existence of a population exposed to a selected pollutant with a given toxicity. Either unpopulated areas or low toxic pollutants will provide a low contribution to this index. Furthermore populated areas, affected by a given pollutant level, will give higher values of the proposed index than those provided by the conventional AQI (1). In order to find out the best value of β, sensitivity tests was conducted on the three studied pollutant episodes. Maps of the new index were calculated with three different values of β. Results showed that the lower is of *1/β* (decrease of the toxicity), the lower is the contribution of the population term (2) on the index "health-environmental" (3).

**Input data**

The above index can be spatialized to provide maps over large urban areas. To do it the new index requires in input of the spatial distribution of the pollutants and the distribution map of population.

The pollutants concentration are usually determined through the use of air quality monitoring stations. Such methodology is limited by the number of observations and by their intrinsic spatial representativeness. The only alternative to the monitoring is the pollutants determination through mathematical models, approach that has been adopted in the development of the present work.

The city of Rome is a typical Mediterranean metropolitan area in which frequent episodes of pollution are verified characterized by elevated concentrations of ozone and particolate, in highly correlation with elevated solar radiation and stagnant conditions. Up to now, the spatial extension of such phenomenon had been determined only through the monitoring stations, but had never been analyzed through complexes modelling calculation including the flows of traffic, the punctual and diffused sources, the meteorology, the pollutants dispersion and the formation of secondary pollutants. The chemical transport model (FARM) has been applied to study primary and secondary gas/aerosol pollutants concentrations in the urban area of Rome during three selected episodes: 20-24 June 2005, 25-29 July 2005 and 9-13 January 2006 (Gariazzo et al [8]). This three episodes represent typical high Ozone and PM episodes, that characterized the city of Rome in both summer and winter seasons.

The application of the chemical transport model (FARM) applied to the city of Rome has allowed the determination of the spatial distribution, on a regular grid 61x61 cells of extension equal area to 1 km$^2$, of the concentrations of pollutants in the area of study during the three examined episodes. It provided the concentrations of primary and secondary pollutants both as gas and aerosol in the urban area of Rome.

The second necessary input for the construction of the index is the distribution of the resident population in the city of Rome, obtained using the results of the census 2001 (the most recent data to our disposition). These data were gridded at the model resolution to provide consistency with air pollution model results.

## 4. RESULTS

The general index (3) has been calculated for every episode in every model cell. The first part of the index "health-environmental" (1) has been calculated using average concentrations of $PM_{10}$ for every episode. Such concentration is calculated averaging, for every model cell, the hourly concentrations during all 5 days of the each episode.

Fig. 1 shows the maps obtained by the first term ($I_{AQI}$) of the proposed index (3) (that it coincides with the AQI of the EPA) during the three selected episodes. During the episode of January, the most elevated concentration of $PM_{10}$ produces the highest values of this term ($I_{AQI}$=70), particularly in the central zone of the city (Arenula). Higher values are also detected in the South zone ($I_{AQI}$=60) in comparison to the North zone of the city ($I_{AQI}$=50). The index $I_{AQI}$ never overcomes the value 100. In the center of the city and in the southern zone, the quality of the air is "Moderate", while it is being "Good" in the area extraurbana and northern of the city.

We calculate the maps of the new index $I_{AQI\text{-}Pop}$ using different values of the coefficient β. Results are shown in figure 2. In can be noticed as with 1/β =1.35 (Fig. 2a) and with 1/β =1 (Fig. 2b) the effect of the population is meaningful on the value of the general index, and the maps, for the different episodes, appear dominated by the contribution of the population term ($I_{pop}$).

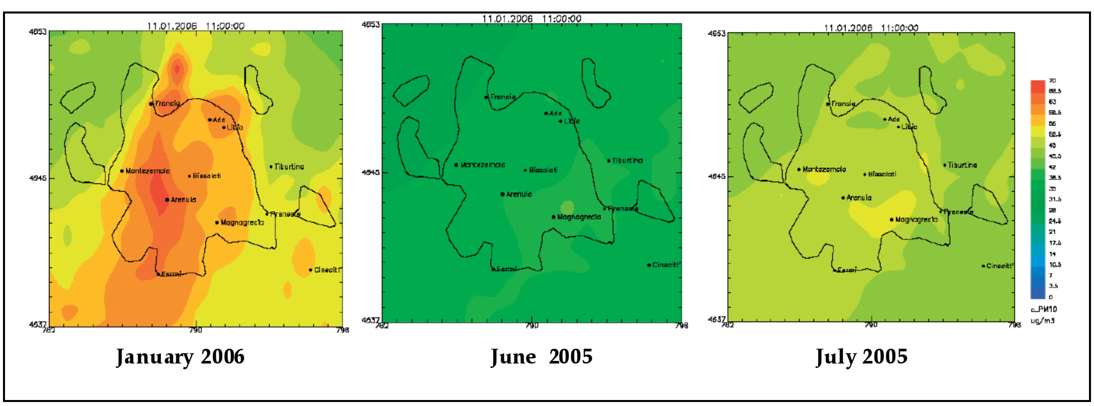


Figure 1. Maps of the index AQI $I_{AQI}$ for the three episodes.

With $1/\beta$ =0,85 (Fig. 2c) the contribution of the population term ($I_{pop}$) looks to be weaker but the structure of the map of the population (Fig. 2a,b) it is still visible. We also evaluate the map using $1/\beta$ =0,5 (not shown here) and the contribution of the population is not more prevailing and the index map has the same spatial distribution as that obtained using only the $I_{inq}$ term (Fig. 1).

The values of $I_{AQI\text{-}Pop}$ are quite different for the different choice of β coefficients: $I_{AQI\text{-}Pop}$ is equal to 450, 150 and 110 for the $1/\beta$ equal to 1,35, 1,00 and 0,85 respectively. This seems suggest that the values of $1/\beta$=0,85 as the more consistent.

It is worth to notice that while the classic AQI results (fig. 1) shows high AQI values in the central area of Rome respect to the other parts of the urban areas, the results obtained using the new index (fig.2c) show an opposite classification (lower values in the center part and higher ones outside it) with a few hot spots in particular locations. This result is due to the contribution of the population term ($I_{pop}$) of the new index, which correctly predicts higher risks in populated areas.

## 5. CONCLUSION

A novel index is presented to evaluate the effects on the human exposure caused by ambient air pollution in urban areas. The index is able to take into account both health risk factors (linked to toxicity and to relative risk RR) and levels of air quality. Usually, these two factors are handled separately and all conventional indexes don't take into account both effects. Our indexes is of additive type and is composed by two terms: one is calculated starting from pollutants concentration and is connected with EPA air quality index (AQI), while the second is composed by an adimensional term based on the population distribution. The index uses adimensional parameters β chosen both to rescale our index to the conventional AQI indexes and to take into account health and environment effects. The given index also allows to obtain maps of "health-environment" risk when it is used in combinations with air pollutant and population density maps. PM10 was considered as studied pollutant. The urban area of Rome was selected as studied area. The PM10 concentrations during three selected episodes were calculated by means of a chemical transport model. The episodes are representative of high Ozone and PM10 concentrations and occurring in summer and winter seasons. "Health-environment" index maps were calculated for all episodes in the studied region.

Sensitivity tests showed that a good balance between AQI and population density terms of the new index can be found using $1/\beta$=0.85 for which only moderate effects on the health is observed to the high value of PM10 levels. Further, we estimated the influence of our $I_{AQI\text{-}Pop}$ indexes on the $PM_{10}$ threshold limit of death and we would found the value of 34,3 $\mu gm^{-3}$ as limit of earliest health effects (this result have to be confirmed with more significant data). A comparison between maps obtained using conventional AQI and those using the new index shows the better information can be provided for the areas affected by high heath-environmental risks.

The new index can contribute to the prevention and/or to the mitigation of the risk "health - environmental" and it will be an useful tool for the planning of the monitoring of quality of the air, for the management of the traffic and for the urbanistic planning.

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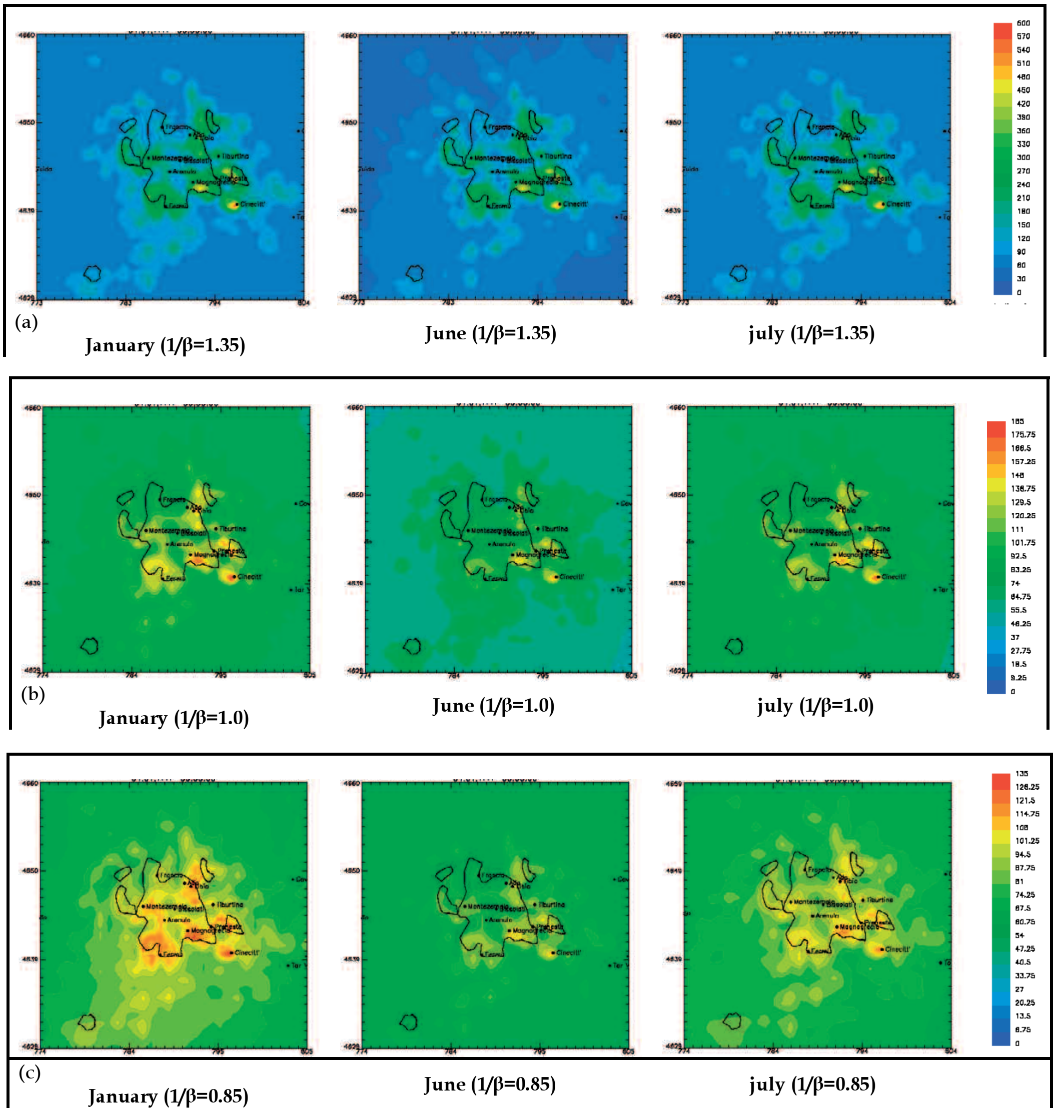


Figure 2. Maps of the index "health-environmental" with different coefficients β for the three examined episodes.