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A short survey on air quality indicators: properties, use, and (mis)use

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Abstract

Purpose – Analysis and comparison of three existing indicators of the air quality: the American air quality index, the French Atmo, and the Italian Indice di Qualità dell'Aria.

Design/methodology/approach – International general and organic regulations to control air quality do not exist yet. Consequently many countries have independently implemented specific indicators to monitor the air pollution and then alert people of resulting health risks. The paper focuses on three of them. Each one is independently presented showing the peculiarities. Therefore, these indicators are compared to identify the features they have in common, as well as those that set them apart, and to figure out which are either restrictive or permissive, and what are their qualities and drawbacks.

Findings – The three mentioned indicators convert the real health risk due to air pollution into numerical information, in different ways. Doing this, they carry out some simplifications or assumptions, which can be questionable. The main difficulty is to understand if the indicators aggregate the different pollutant concentrations consistently with the real effects on human health.

Research limitations/implications – This paper analyses only three specific indicators of the air quality, selected among the existing ones.

Practical implications – Indicators should carefully be analysed to understand if they properly represents the real effects of pollutants on human health. The most critical aspect to consider is the aggregation of the different pollutant concentrations in one information.

Originality/value – This paper analyses the efficacy of representation of some air quality indicators. It discusses if indicators aggregation is consistent with the real effects on human health.

Keywords Air, Health and safety, Risk management

Paper type Research paper

1. Introduction

As a consequence of the frightening increase in air pollution, especially in large urban areas, many international organizations and governments have adopted a series of regulations to keep low the level of pollutant concentration. Since people incessantly breathe in the atmosphere, the presence of pollutants is very dangerous for human health. For several years, a thorough scientific research has been carried out in order to find out how much the pollutants diffused in the air affect people. This activity is carried out monitoring chemically and physically the environment, and also using biological indicators to evaluate the impact the pollutants have on the ecosystem and on people (Rapport *et al.*, 2003). For instance, several studies established that nitrogen dioxide (NO_2) and ozone (O_3) increase the risk of death in patients with severe asthma (Sunyer *et al.*, 2002). Ozone polluting the air generates an increase of the lung cancer (Yang *et al.*, 2005). Traffic-related air pollution increase mortality (Hoek *et al.*, 2003).

Ozone and carbon monoxide (CO) are linked to cardiac birth deficiencies (Ritz *et al.*, 2002), etc. In order to prevent the pollutant concentration from being dangerous to health, in several areas the competent authorities sometimes have to take extraordinary measures, such as the limited or total restriction of traffic circulation.

Public awareness of this problem has been increased considerably in the past few years due to media campaigns. A high level of air pollution is not only harmful and annoying to the population, but is also a heavy drain on the wealth of a country. The health damages generate several additional charges relating to:

- health service;
- mobility and absence from school or work due to sickness; and
- monitoring and protection of the environment.

For this purpose, several countries have introduced evaluation methods that rapidly and efficiently indicate the air quality condition for the population. First, the US Environmental Protection Agency (EPA) developed the air quality index (AQI) (United States Environmental Protection Agency, 1999). This indicator provides air quality information using numeric and chromatic indicators, in order to report immediately and extensively the level of risk for the human health.

Other European countries have followed the way. The following sections illustrate the Atmo index – formulated and made operational by the French Environment Ministry (Ministère de l'écologie et du développement durable, 2004) – and the Indice di Qualità dell'Aria (IQA) index – developed and made operative in some northern regions of Italy: Piedmont, Lombardy, etc. (Regional law 43, 2000). These indicators are similar in pattern, but are operated in different ways. Briefly, they take into account the concentrations of the main air pollutants (usually measured by $\mu g/m^3$), and set a tolerability scale for each pollutant, trying to gather general information on the overall air condition.

After a general presentation, this paper will focus on the specific characteristics of each indicator and on their mutual differences. The survey has been conducted within the Department of Production Systems and Business Economics (DISPEA) of Politecnico di Torino (Italy).

2. The American Air Quality Index (AQI)

The AQI is reported for the metropolitan statistical areas (MSAs) of US, with population of more than 350,000 – according to the Clean Air Act safety limits of five air pollutants: ozone (O_3), particulate matter (PM), carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) (US EPA, 1999).

In each area, the previous 24 hours concentrations of the five mentioned pollutants is measured (or estimated) and reported on six reference categories (Table I).

According to the Clean Air Act, an AQI value is 100 or less for an acceptable concentration of each pollutant. Therefore, AQI values lower than 100 are judged admissible. For higher AQI values, the air is unhealthy for the most sensitive subjects first, and as the air pollution increases it becomes unhealthy also for the general population. It is interesting to notice that the above-mentioned thresholds are considerably higher than the European Union (EU) regulations. These last limits are quoted in Table II.

For each area, the daily AQI value is given by the worst registered condition among the five pollutants:

$$\mathrm{AQI} = \max\{I_{\mathrm{O_3}}, I_{\mathrm{PM_{10}}}, I_{\mathrm{CO}}, I_{\mathrm{SO_2}}, I_{\mathrm{NO_2}}\} \tag{1}$$

Given the pollutants' concentration data and the breakpoints in Table I, every AQI sub-index is calculated using the following equation (linear interpolation):

$$I_p = I_{\mathrm{L},p} + \frac{I_{\mathrm{H},p} - I_{\mathrm{L},p}}{\mathrm{BP}_{\mathrm{H},p} - \mathrm{BP}_{\mathrm{L},p}}(C_p - \mathrm{BP}_{\mathrm{L},p}) \tag{2}$$

where I_p, the sub-index for the pth pollutant; C_p, the concentration of the pth pollutant; $\mathrm{BP}_{\mathrm{H},p}$, the breakpoint that is greater than or equal to C_p; $\mathrm{BP}_{\mathrm{L},p}$, the breakpoint that is less than or equal to C_p; $\mathrm{I}_{\mathrm{H},p}$, the AQI value corresponding to $\mathrm{BP}_{\mathrm{H},p}$; $\mathrm{I}_{\mathrm{L},p}$, the AQI value corresponding to $\mathrm{BP}_{\mathrm{L},p}$.For instance suppose you have an 8-hour ozone (O_3) concentration of 187 μg/m^3. Then you look in Table I for the range that contains this concentration (first column, third row), which is placed between the breakdowns $\mathrm{BP}_{\mathrm{L,O_3}} = 181\,\mu\mathrm{g/m^3}$ and $\mathrm{BP}_{\mathrm{H,O_3}} = 223\,\mu\mathrm{g/m^3}$, corresponding to the sub-index values of $I_{\mathrm{L,O_3}} = 101$ to $I_{\mathrm{H,O_3}} = 150\,\mu\mathrm{g/m^3}$. So an ozone concentration of $187\,\mu\mathrm{g/m^3}$ corresponds to a sub-index given by the equation:

Table I.
The six reference categories of the five pollutants embraced by the AQI

O_3, 8 hour mean value (μg/m^3)	PM_{10}, 24 hour mean value (μg/m^3)	CO, 8 hour mean value (μg/m^3)	SO_2, 24 hour mean value (μg/m^3)	NO_2, 1 hour mean value (μg/m^3)	AQI, reference values
0-137	0-54	0-5.5	0-97	[a]	0-50
138-180	55-154	5.6-11.76	98-412	[a]	51-100
181-223	155-254	11.77-15.5	413-640	[a]	101-150
224-266	255-354	15.6-19.25	641-869	[a]	151-200
267-800	355-424	19.26-38.0	870-1,727	1,330-2,542	201-300
>800	425-604	38.1-50.5	1,728-2,300	2,543-4,182	301-500

Notes: The calculation method and the breakpoints of the reference categories are specified for every pollutant (US EPA, 1999). [a]CE regulations do not set a nitrogen dioxide (NO_2) short-term limit. They only define a yearly mean value of 100 μg/m^3. In the AQI calculation the nitrogen dioxide is considered uniquely if the hourly mean concentration is higher than 1,330 μg/m^3 (so according to AQI reference values upper than 200)

Table II.
EU regulations air pollutant upper limits

O_3, 8 hour mean value (μg/m^3)	PM_{10}, 24 hour mean value (μg/m^3)	NO_2, yearly mean value[a] (μg/m^3)
120	150	100

Notes: [a]CE regulations do not set a nitrogen dioxide (NO_2) short-term limit. They only define a yearly mean value of 100 μg/m^3. In the AQI calculation the nitrogen dioxide is considered uniquely if the hourly mean concentration is higher than 1,330 μg/m^3 (so according to AQI reference values upper than 200)
Source: (Dir 96/62/EC and daughter directives, 1996)

$$I_{O_3} = I_{L,O_3} + \frac{I_{H,O_3} - I_{L,O_3}}{BP_{H,O_3} - BP_{L,O_3}}(C_{O_3} - BP_{L,O_3}) = 101 + \frac{150 - 101}{223 - 181}(187 - 181) = 108$$

Now consider the air condition in Table III.

The sub-indexes values are, respectively:

$$I_{O_3} = I_{L,O_3} + \frac{I_{H,O_3} - I_{L,O_3}}{BP_{H,O_3} - BP_{L,O_3}}(C_{O_3} - BP_{L,O_3}) = 51 + \frac{100 - 51}{180 - 138}(165 - 138) = 82$$

$$\begin{aligned} I_{PM_{10}} &= I_{L,PM_{10}} + \frac{I_{H,PM_{10}} - I_{L,PM_{10}}}{BP_{H,PM_{10}} - BP_{L,PM_{10}}}(C_{PM_{10}} - BP_{L,PM_{10}}) \\ &= 101 + \frac{150 - 101}{254 - 155}(158 - 155) = 102 \end{aligned}$$

$$I_{CO} = I_{L,CO} + \frac{I_{H,CO} - I_{L,CO}}{BP_{H,CO} - BP_{L,CO}}(C_{CO} - BP_{L,CO}) = 51 + \frac{100 - 51}{11.76 - 5.6}(10.5 - 5.6) = 90$$

$$I_{SO_2} = I_{L,SO_2} + \frac{I_{H,SO_2} - I_{L,SO_2}}{BP_{H,SO_2} - BP_{L,SO_2}}(C_{SO_2} - BP_{L,SO_2}) = 0 + \frac{50 - 0}{97 - 0}(66 - 0) = 34$$

The AQI is 102 with PM_{10} as the responsible pollutant.

$$AQI = \max\{I_{O_3}, I_{PM_{10}}, I_{CO}, I_{SO_2}\} = \max\{82, 102, 90, 34\} = 102$$

Each AQI value is linked with a colour and with an air quality descriptor. The AQI scale is split into six reference categories by EPA – the same reported in Table I. The more the AQI value increases, the more the population health risk increases (Table IV).

O_3 (μg/m^3)	PM_{10} (μg/m^3)	CO (μg/m^3)	SO_2 (μg/m^3)
165	158	10.5	66

Table III. Air pollutant values registered in a particular metropolitan area

AQI reference values	Descriptor	Colour
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for sensitive groups	Orange
151-200	Unhealthy	Red
201-300	Very unhealthy	Purple
301-500	Hazardous	Maroon

Source: (US EPA, 1999)

Table IV. American AQI categories, descriptors, and colours

For example, when the AQI is 50, the air quality is good with a little level of risk, and the associated colour is green. Vice-versa for AQI higher than 300, the air quality is bad with a high level of risk, and the associated colour is maroon.

The EPA qualitative description related to the AQI categories are as follows:

1. "good": the AQI value is within 0-50 range. The air quality is satisfactory, with very little risk to the population.
2. "moderate": AQI included between 51 and 100. The air quality is admissible, however few people could be healthy damaged because of the presence of pollutant. For instance, ozone sensitive people may experience respiratory symptoms.
3. "unhealthy for sensitive groups": outdoor active children and adults with respiratory disease are at risk due to the ozone exposure, whereas people with cardiovascular disease are most at risk due to the carbon monoxide exposure. When the AQI value is included between 101 and 150 these sensitive individuals could increase their symptoms of disease to the point of health compromising. However, much of the population is not at risk in that condition.
4. Within the 151-200 range the AQI is considered to be "unhealthy". This situation causes possible disease for the general population. Sensitive individuals could be damaged more seriously.
5. "Very unhealthy" AQI values – between 201 and 300 – represent an alarm. The whole population could be health damaged seriously.
6. "Hazardous" – over 300 – AQI values trigger an immediate alarm. The whole population can be involved in great disease.

The index put the emphasis on the risk condition of the groups most sensitive to air pollutant like children, elderly people, and people with respiratory or cardiovascular disease.

Adequate communications support the AQI utilization and make it available to population. The AQI report is easily accessible through mass-media, announcements in places of public access, web sites, etc. The colour format – which represents the listed categories, the pollution level and the linked health risk – makes people able to know and properly react to the existing circumstances.

2.1 The AQI property of non-monotony

In reference to the example data in Table III, let suppose the carbon monoxide concentration increases driving the corresponding index I_{CO} to 102. The new condition is surely pejorative compared to the previous one (two of the four sub-indexes have a value of 102). Nevertheless, the AQI indicator remains unchanged and it does not properly represent significant air pollution changes. Therefore, the AQI does not fulfil the property of monotony (Bouyssou *et al.*, 2000).

2.2 The AQI property of non-compensation

Let suppose to calculate the AQI considering the two different air quality conditions (W and Z) in Table V. The first set of data (W) is almost perfect except for the PM_{10} concentration; instead, the second one (Z) is not particularly good for all the sub-indexes. Nevertheless, the AQI is 155 in the situation W and it is 130 in the situation Z. Unlike other indicators, the AQI does not fulfil any sub-index compensation.

2.3 *The AQI sub-indexes scale construction*

In regard to Table I it clearly appears that a “homogeneous mapping” – between each pollutant concentration bandwidth and the corresponding sub-index variation size – is lacking. Considering, for example, the SO_2 pollutant, you notice the first AQI level relates the (0-97 $\mu g/m^3$) range of concentration and the (0-50) sub-index range; otherwise the second AQI level link is between the (98-412 $\mu g/m^3$) range of concentration and the (51-100) sub-index range. The AQI level range width is constant, but the width of the range of concentration differs. Each pollutant range size is fixed on the basis of the pollutant concentration effects on human health. This assumption partly contrasts with the direct proportionality assumption between the air pollutant concentration and the AQI within each specific range (equation (1)).

3. The Atmo index

The Atmo index has been developed by the French Environment Ministry. It is based on the concentration of four air pollutants: ozone (O_3), particulate matter (PM), sulphur dioxide (SO_2), and nitrogen dioxide (NO_2). Each of the pollutants is related to a sub-index. The Atmo value is the maximum of the four sub-indexes (equation (3)).

$$\text{Atmo} = \max\{I_{O_3}, I_{PM}, I_{SO_2}, I_{NO_2}\} \tag{3}$$

Each pollutant concentration is measured and reported on a ten-level scale. The first level corresponds to an excellent air quality, the fifth and sixth level are just around the European “long term” norms, the eighth level corresponds to the EU “short term” norms, and finally the tenth level corresponds to a health hazard condition. The sub-indexes’ ten-level scales are shown in Table VI. The PM_{10} value is the (great) mean of the daily mean values, registered from 1:00 to 24:00 in the different operative stations of the monitored area. The value of the other pollutants is the mean of the maximum hourly values, registered from 1:00 to 24:00 in the different operative stations of the monitored area.

To better describe the Atmo directions for use, consider the air condition in Table VII.

Coherently with equation (3), the Atmo index value is 8. In this specific condition the air quality is very unhealthy. A dissertation about the Atmo main properties is reported in the next sections.

3.1 *The Atmo property of non-monotony*

Let imagine a sunny day with heavy traffic and no wind. In reference to the example data in Table VII, let suppose the ozone concentration increases driving the corresponding index from 3 to 8. The new condition is surely pejorative compared to the previous one (two of the four sub-indexes have a value of 8). The Atmo indicator

Condition	I_{O_3}	$I_{PM_{10}}$	I_{CO}	I_{SO_2}
W	30	155	25	30
Z	90	130	100	80

Note: Although some pollutant concentrations (O_3, CO and SO_2) are worse in the condition *Z*, the AQI is higher for the condition *W*

Table V.
AQI sub-indexes values in two air quality conditions

Table VI. Ten reference categories of the four sub-indexes which make up the Atmo indicator

Level	PM_{10}($\mu g/m^3$) Min	Max	NO_2($\mu g/m^3$) Min	Max	O_3($\mu g/m^3$) Min	Max	SO_2($\mu g/m^3$) Min	Max	Descriptor	Colour
1	0	9	0	29	0	29	0	39	Very good	Green
2	10	19	30	54	30	54	40	79	Very good	Green
3	20	29	55	84	55	79	80	119	Good	Green
4	30	39	85	109	80	104	120	159	Good	Green
5	40	49	110	134	105	129	160	199	Medium	Orange
6	50	64	135	164	130	149	200	249	Poor	Orange
7	65	79	165	199	150	179	250	299	Poor	Orange
8	80	99	200	274	180	209	300	399	Bad	Red
9	100	124	275	399	210	239	400	499	Bad	Red
10	≥125		≥400		≥240		≥500		Very bad	Red

Note: Each level is set out between a minimum and a maximum breakpoint value (Ministère de l'écologie et du développement durable, 2004)

Table VII. Atmo sub-indexes encoding

Pollutant	NO_2	SO_2	O_3	PM_{10}
Sub-index	2	2	3	8

Note: The Atmo index value is 8

value would be expected to be higher than the previous one. Nevertheless, the Atmo indicator remains unchanged at the value of 8 and it does not properly represent significant air pollution change. This proves that the Atmo does not fulfil the property of monotony.

3.2 The Atmo property of non-compensation

Suppose the calculation of the Atmo by considering the two different air quality conditions (U and V) in Table VIII. The first set of data (U) is almost perfect except for the O_3 concentration; instead, the second one (V) is not particularly good for all the sub-indexes. Nevertheless, the Atmo is 7 in the situation U and it is 6 in the situation V.

In this case, the Atmo sub-indexes do not compensate each other. In the state U, the high O_3 value is not counterbalanced by the three remaining sub-indexes' low values.

3.3 The Atmo sub-indexes scale construction

The Atmo indicator, as well as the AQI, lacks a "homogeneous mapping" between each pollutant concentration bandwidth and the corresponding sub-index range size (Table VI). For example by considering the SO_2 pollutant, the first Atmo level is related

Table VIII. Atmo sub-indexes values in two air quality conditions

Condition	NO_2	SO_2	O_3	PM_{10}
U	2	1	7	1
V	6	4	6	6

Note: Although some Y condition pollutant concentrations (NO_2, SO_2 and PM_{10}) are worse, the Atmo index is higher for the X condition to the (0-39 μg/m^3) range of concentration (bandwidth of 39 μg/m^3), and the sixth Atmo level is related to the (200-249 μg/m^3) range of concentration (bandwidth of 49 μg/m^3). As stated above for the AQI, each Atmo range size is fixed on the basis of the pollutant concentration effects on human health. Every value of the pollutant concentration, in the same Atmo reference level, is supposed to be equivalent. An SO_2 concentration of 201 μg/m^3 has to be considered equivalent to a 249 μg/m^3 concentration, according to the effects on human health.

Incidentally, it is interesting to see that the concentration values, which bound the Atmo reference levels, are considerably smaller than the AQI ones.

4. The IQA index

In some Northern Italian regions (Piedmont, Lombardy, etc.) different systems are currently being tested to monitor the air quality and provide information to the public. The analysis will focus on the IQA index , made operative in Piedmont (Piedmont Regional Law 43/2000, 2000). The index is inspired by the US EPA AQI (Section 2), but with some clear differences.

According to the safety regulation limit, the IQA aggregates the most critical air pollutants at each time of the year on the basis of their effects on human health: ozone (O_3) and particulate matter (PM_{10}) in summertime, PM_{10} and nitrogen dioxide (NO_2) in wintertime.

The IQA index constitutes a popular communication system that extensively provides the monitored air quality condition. By considering the current standard, it represents the air quality level, and, therefore, also the human health risk.

The IQA is expressed by a numerical index between 1 and 7; the higher the air pollution is, the more serious the health hazard is and the higher the index value is.

The IQA index comprises several sub-indexes, each of which is related to a monitored pollutant: ozone (O_3), particulate matter (PM_{10}) and nitrogen dioxide (NO_2). The IQA value is the arithmetic mean of the two maximum sub-indexes' values (equation (4)).

$$\mathrm{IQA} = \frac{I_1 + I_2}{2} \tag{4}$$

where I_1 and I_2 are the two sub-indexes (among the three critical pollutants PM_{10}, O_3, NO_2) with the higher value.

The IQA is daily calculated using the previous 24-hours values of the concentrations of pollutants. The IQA numerical value is converted into a 7 level reference scale, featured in Table IX. This final class rank is presented to the population. This information is enriched by an indication of the air pollution evolution, derived from the weather forecast.

Briefly, IQA is a conventional indicator used to:

- report the quality of the air on a daily basis;
- identify the worst environmental parameters; and
- calculate the amount of risk that the population is subjected to.

A numeric value of IQA equal to 100 essentially corresponds to the air quality safety level for polluting substances. IQA values less than 100 are generally satisfactory with no potential hazard for public health. The more the IQA value is over 100, the more the air quality is considered unhealthy – initially only for the most sensitive groups of people and then for all the population.

Different descriptions of the air quality, different colours, and some useful advice for the population are associated with each of the seven IQA levels:

1. "excellent" – blue, with a numeric IQA value between 0 and 50. The quality of the air is considered excellent.
2. "good" – light blue, with a numeric IQA value between 51 and 75. The air quality is considered very satisfactory with no risk for the population.
3. "fair" – green, with a numeric IQA value between 76 and 100. The air quality is satisfactory and there is no risk for the population.
4. "mediocre" – yellow, with a numeric IQA value between 101 and 125. The population is not at risk. People with asthma, chronic bronchitis or heart problems might show symptoms of slight breathing problems, but only during intense physical activity; it is advised that this category of people limit their physical exercise outdoors, especially during the summertime.
5. "not very healthy" – orange, with a numeric IQA value between 126 and 150. People with heart problems, the elderly and children may be at risk. It is advised that these categories of people limit their physical activity and prolonged periods of time outdoors, especially during the peak daytime hours in summertime.
6. "unhealthy" – red, with a numeric IQA value between 151 and 175. Many people could have slightly negative health problems, albeit reversible; it is advised to limit extended periods of time outdoors, especially in the peak daytime hours in summertime. People in the sensitive groups could, however, may have more serious symptoms; in these cases it is highly recommended expose oneself as little as possible to the open air.
7. "very unhealthy" – purple, with a numeric IQA value above 175. There may be slightly negative effects on the health of all people in the area. The elderly and people with respiratory problems (breathing difficulties) should avoid going outside. Other people (especially children) should avoid doing physical activity and limit their time outdoors, especially during the peak daytime hours in summertime.

Table IX.
IQA categories, descriptors and colours (Piedmont Regional law 43/2000, 2000)

IQA reference values	IQA final rank	Descriptor	Colour
0-50	1	Excellent	Blue
51-75	2	Good	Light blue
76-100	3	Fair	Green
101-125	4	Mediocre	Yellow
126-150	5	Not very healthy	Orange
151-175	6	Unhealthy	Red
≥ 176	7	Very unhealthy	Purple

The IQA sub-indexes are:

Nitrogen dioxide (NO_2) sub-index: I_{NO_2}

$$I_{NO_2} = \frac{\bar{V}_{\max h_{NO_2}}}{V_{\mathrm{rif} \quad h_{NO_2}}} \cdot 100 \qquad (5)$$

$\bar{V}_{\max h_{NO_2}}$	is the mean of the maximum hourly NO_2 concentration values, registered from 1:00 to 24:00 in the different operative stations of the monitored area;
$V_{\mathrm{rif}\, h_{NO_2}}$	is a NO_2 concentration reference value (200 μg/m^3), which represents a hourly safety limit (DM 2.04.2002 n. 60, 2002).

Particulate matter (PM_{10}) sub-index: $I_{PM_{10}}$

$$I_{PM_{10}} = \frac{\bar{V}_{\mathrm{med}\,24\,h_{PM_{10}}}}{V_{\mathrm{rif}_{PM_{10}}}} \cdot 100 \qquad (6)$$

$\bar{V}_{\mathrm{med}\,24\,h_{PM_{10}}}$	is the arithmetic mean of the average hourly PM_{10} concentration values, registered from 1:00 to 24:00 in the different operative stations of the monitored area;
$V_{\mathrm{rif}_{PM_{10}}}$	is a PM_{10} concentration reference value (50 μg/m^3), which represents a daily safety limit (DM 2.04.2002 n. 60, 2002).

Ozone (O_3) sub-index: $I_{8\,h_{O_3}}$

$$I_{8\,h_{O_3}} = \frac{\bar{V}_{\max 8\,h_{O_3}}}{V_{\mathrm{rif}\,8\,h_{O_3}}} \cdot 100 \qquad (7)$$

$\bar{V}_{\max 8\,h_{O_3}}$	is the mean of the maximum O_3 concentration values, registered every 8 hours, and calculated every hour on the basis of the previous 8 hours, from 1:00 to 24:00 in the different operative stations of the monitored area;
$V_{\mathrm{rif}\,8\,h_{O_3}}$	is a O_3 concentration reference value (120 μg/m^3), which represents a 8-hours safety limit (Dir. 2000/3/CE).

The index value is calculated using the data from the previous day. For this reason the index report needs to be associated to prognostic information that give a pointer to the air quality, at the time the reading is taken.

To allow an evolution's assessment of the atmospheric pollution, the index value of the previous day is reported together with the index values from the six previous days.

As an example, let show the calculation of the IQA index for Turin's metropolitan area for 27 January 2005. The data for each pollutant can be seen in Table X (Province of Turin's regional agency for the environment – ARPA, 2005).

The first three pollutants are used to calculate the IQA value. The associated sub-indexes are, respectively:

$$I_{NO_2} = \frac{125}{200} \cdot 100 = 62.5; \quad I_{PM_{10}} = \frac{84}{50} \cdot 100 = 168; \quad I_{8\,h_{O_3}} = \frac{33}{120} \cdot 100 = 27.5$$

The two maximum values refer to PM_{10} and to NO_2. The IQA index value is:

$$\mathrm{IQA} = \frac{I_{NO_2} + I_{PM_{10}}}{2} = \frac{62.5 + 168}{2} = 115.3$$

This value corresponds to level 4 (mediocre) according to the IQA scale indicated in Table IX.

4.1 The IQA property of non-monotony

The IQA indicator is not monotonous. Taking into consideration the data in Table X, one supposes that the sub-index "ozone" goes from 27.5 to 61. This latter condition (obviously worse than the previous one) is still described by the same IQA indicator value (115.3). Also in this case the IQA indicator does not adequately evaluate significant changes in the concentration of pollutants.

4.2 The IQA property of compensation

Let suppose to calculate the IQA considering the two different air quality conditions (*A* and *B*) in Table XI.

Table X.
Values of pollutants found in Turin's metropolitan area on 27 January 2005

O_3(μg/m^3)	PM_{10} (μg/m^3)	NO_2 (μg/m^3)	C_6H_6 (μg/m^3)	CO (μg/m^3)	SO_2 (μg/m^3)
33	84	125	5.6	2.2	15

Source: (ARPA, Province of Turin, 2005)

Table XI.
Concentrations of pollutants in two air quality conditions

Condition	PM_{10} (μg/m^3)	O_3 (μg/m^3)	NO_2 (μg/m^3)
A	84	33	125
B	31.25	33	336

Note: Although the concentrations are different, the IQA index value is the same

The IQA associated sub-indexes' values are, respectively:

$$I(A)_{\mathrm{NO_2}} = \frac{125}{200} \cdot 100 = 62.5; \quad I(A)_{\mathrm{PM_{10}}} = \frac{84}{50} \cdot 100 = 168;$$

$$I(A)_{8\,\mathrm{h}_{O_3}} = \frac{33}{120} \cdot 100 = 27.5$$

$$I(B)_{\mathrm{NO_2}} = \frac{336}{200} \cdot 100 = 168; \quad I(B)_{\mathrm{PM_{10}}} = \frac{31.25}{50} \cdot 100 = 62.5;$$

$$I(B)_{8\,\mathrm{h}_{O_3}} = \frac{33}{120} \cdot 100 = 27.5$$

In both conditions, the two maximum values refer to the PM_{10} and NO_2 sub-indexes, and drive the IQA indicator to the same value:

$$\mathrm{IQA}(A) = \mathrm{IQA}(B) = \frac{I_{\mathrm{NO_2}} + I_{\mathrm{PM_{10}}}}{2} = \frac{62.5 + 168}{2} = 115.3$$

Based on the health risk estimated by the IQA index, the two previous conditions are considered equivalent. We can define a sort of "substitution rate" (equation (4)):

$$\Delta(I_{\mathrm{NO_2}}) = -\Delta(I_{\mathrm{PM_{10}}})$$

in terms of pollutants' physical concentration (apply equation (5) and (6)):

$$\frac{\Delta \bar{V}_{\max \mathrm{h}_{\mathrm{NO_2}}} \cdot 100}{200} = -\frac{\Delta \bar{V}_{\mathrm{med} \quad 24\,\mathrm{h}_{\mathrm{PM_{10}}}} \cdot 100}{50}$$

where:

$\Delta \bar{V}_{\max \mathrm{h}_{\mathrm{NO_2}}}$ variation in the NO_2 concentration

$\Delta \bar{V}_{\mathrm{med}\, 24\,\mathrm{h}_{\mathrm{PM_{10}}}}$ variation in the PM_{10} concentration

from which it follows that:

$$\Delta \bar{V}_{\max \mathrm{h}_{\mathrm{NO_2}}} = -4 \cdot \Delta \bar{V}_{\mathrm{med}\, 24\,\mathrm{h}_{\mathrm{PM_{10}}}}$$

A 1 μg/m^3 variation in concentration of PM_{10} is balanced out by a 4 μg/m^3 variation in concentration of NO_2. Does such a "substitution rate" exist on the basis of the risk of damages to human health too?

4.3 Construction of IQA sub-index scale

According to the linear proportionality formulas given in the equation (5)-(7), there is a uniform "mapping" between the concentrations of the pollutant and the values of the IQA indicator.

The calculation of each sub-index is influenced by the values established in reference to the regulations for the protection of human health (DM 2.04.2002 n. 60, Dir 96/62/EC and following daughter directives). Possible changes of reference values may have direct consequences on single part of the sub-indexes and on the possibility to compare them over time. On the other hand, the normative reference values are not clearly mentioned in the definition of the AQI and Atmo indicators.

The equation (4), which identifies the IQA indicator with the average of the two most critical sub-indexes, is worthy of a special remark. What are the sub-indexes and the IQA's scaling properties? Regarding the possibility of calculating the average, the conventional IQA scale automatically acquires the interval property (Franceschini, 2001). Is that right? The average of the two most critical sub-indexes is really the best model of the problems for the human health?

Finally, is significant to notice that the IQA reference values of PM_{10}, O_3 and NO_2 are considerably lower than the AQI ones.

4.4 Comments on indicators meaning

Let consider the statement: "Today's AQI value is twice (150) as much as yesterday's (75)". Does it make sense? What are the AQI index scaling properties? We will demonstrate the meaninglessness of this statement.

Let go back to the AQI sub-indexes definition. The concentration of each pollutant is given in $\mu g/m^3$. The conversion into the AQI scale (Table I) is totally arbitrary. For instance, – instead of attributing the values (0-50) to the O_3 pollutant concentrations (0-137 $\mu g/m^3$), and the values (51-100) to the concentrations (138-180 $\mu g/m^3$) – the values (0-40), (41-80) could have been assigned to them. In both the encoding the AQI indicator preserves the same properties.

The most significant information the indicators provide is not the encoded value itself, but the capacity to make clear the air pollutant tolerability conditions, according to the health risk official standards. The six level encoding is only a way to make the information practical for the user. The AQI sub-indexes scales have only the ordering property. The values of the pollutants concentrations are tied to a level digit, without any rule of linear proportionality. Therefore, the statement "Today the ozone sub-index is higher than yesterday" is reasonable. On the other hand, the statement: "Today the AQI index is higher than yesterday" has to be considered with attention. The AQI overall indicator does not fulfil the property of monotony (Section 3.1).

Some questions arise when different sub-indexes produce the same AQI index value. An AQI value (51-100) due to the SO_2 sub-index can be compared with the same value due to the PM_{10} sub-index to what extent? What are the risks of the pollutant interactions on health?

Of course the competent authorities have carefully built the sub-indexes' scales, considering the single pollutant effects on health. For instance, each sub-index interval (51-100) is linked to the specific pollutant concentration that is tolerated in the American standards. A question on the concept of equivalence is still open. Some pollutants could damage the human health in the short term, others requires a longer time. The effect can be different in the different parts of the body, and so on.

In conclusion, how a possible disease can be estimated? . . . on the physical damages; . . . the health expenses; . . . the mortality rate . . .?

5. Air quality indicators comparison

In the previous sections, the paper has indicated some similarity but also substantial differences, among the three air quality indicators: AQI, Atmo, IQA.

Although the considered pollutants are quite the same (PM_{10}, O_3, NO_2, SO_2 ...), generally the indicators are differentiated by:

- the calculation of the sub-indexes;
- the number of classes of risk;
- the reference categories of the concentrations;
- the criteria of synthesis of sub-indexes; and
- the sub-indexes' compensation property.

These distinctions emphasize how the same physical phenomenon can be represented in different ways. Nevertheless, with reference to the concentration of the same pollutants, should the health risk be the same?

A common aspect of the three discussed indicators is that, for a definite value they have, the main responsible pollutant is not made explicit. In other words, each aggregative indicator has not memory for the most critical pollutant concerned. For example, if the Atmo index is 6, we cannot know what is the sub-index, which is the main cause responsible for this result. The same goes for AQI and IQA.

It is significant to confirm that indicators are not measure, although they are defined on the basis of physical values. Given a particular combination of air pollutants, each of the three indicators leads to a different model. Each indicator maps the pollutants' real concentrations into a different scale, whose level number and range values are absolutely conventional (Finkelstein, 2003).

Another significant aspect of the three indicators is that the environmental conditions, which they are connected to, can be much different. For instance, if the Atmo is 8, the most critical sub-index may possibly be either SO_2 or PM_{10}. Several different concentrations of the air pollutants are supposed to be equally dangerous for the human health (Table VI). In other terms, comparable overall indexes don't entail comparable physical concentrations of the air pollutants.

6. Conclusions

This short paper about three different air quality indicators shows some remarkable features. First of all, although the indicators are based on the same input information (the physical concentrations of the main air pollutants) they aggregate these data differently and they lead to different outputs. The AQI reports the concentration of every pollutant on a six level scale, and – for each level – its value is depending on the level of the most critical pollutant. The Atmo index reports the concentration of every pollutant on a ten level scale and takes the value of the highest level. Finally, the IQA reports the concentration of every pollutant on a six level reference scale. Its value is calculated as the average of the two highest-level values.

Basically, these indicators convert the real health risk due to air pollution into numerical information in different ways. Doing this, they simplify or assume elements which can be questionable. For example, some indicators are indifferent to the change of the least critical pollutants and they do not fulfil the property of monotony. Others enable compensations among sub-indexes. Given a particular air condition, the reduction of one or more sub-indexes can be counterbalanced by the increase of others, without any changes in the final value.

This paper has dealt with the problem of the air quality representation, showing the particular features of some practical methods used. The main difficulty is to understand if the indicators aggregate the different pollutants consistently with their general effect on the human health. The issue is still open and open is the definition of the set of properties that an air quality indicator should possess (Melnyk *et al.*, 2004).

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Further reading

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