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CLASSIFICATION OF AIR QUALITY BASED ON FACTORS OF RELATIVE RISK OF MORTALITY INCREASE

The study presents the modified formula of air quality index, based on Cairncross's concept of *API* index (DAPPS system for Cape Town, South Africa), enabling an assessment of additive effects of short-term exposure to the main air pollutants. The *API* index refers directly to health risk, since it is based on the factors of the total incremental daily mortality risk. The results of air quality classification using modified *API* were exemplified by the data originating from the monitoring station in Dąbrowa Górnicza (urban background) for the year 2006.

1. INTRODUCTION

The adverse effect of ambient air pollutants on the respiratory or cardiovascular system manifests itself mainly as various ailments. Literature on the subject demonstrates the numerous examples of insufficiency and death due to the reasons referred to above (quality description). The quantity description – the evaluation of the essential cause-and-effect relationships – is much more complex. The difficulties in describing the exposure–response relationship result from the following reasons: low concentrations, diverse individual sensitivity, adaptation effect, and other environmental effects. In practice, the cause-and-effect relationship is defined in two ways: (1) by settling the threshold concentrations, below which the adverse health effects are not observed (a toxicological approach) or (2) using the probability function for the occurrence of the specified health outcomes, on the assumption that there are no threshold concentrations which are safe for health (a risk-based approach). The latest WHO research supports the latter approach. It was stated that in the case of PM10, PM2.5 and O_3 there are no concentrations, below which the risk of adverse health effect is zero. This probably also refers to SO_2 and NO_2. It is believed that in a traditional toxicological sense, the threshold concentration has been found only for one of

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main atmospheric pollutants, i.e. for CO [1]. In the light of this research, the guideline concentrations for most of main pollutants, determined for the purposes of health protection, raise doubts. In many cases, the air quality standards should be treated as a result of compromise in favour of the technical capabilities for limiting the emission.

The air quality index (*AQI*) is the kind of daily announcement made for the public, which describes the air quality in a simple, understandable way. The aim of the index calculation is to warn against the situations, which may be potentially hazardous to health. The concept of air quality classification was formulated in the 1960ies, and it became popular in Europe in the 1990ies [2]. Later attempts to work out the common European *AQI* formula proved unsuccessful. Poland is one of few European countries, which has not developed its own index.

The traditional *AQI* formulas, referring to the air quality standards, take into account neither synergistic nor even additive effects of common pollutants, because an overall index is set at the highest value of the sub-index for the pollutants considered. Hence, there are more and more opinions criticizing such an approach and the propositions relating to the alternative solutions [3]–[5]. An interesting proposal, based on WHO methodology and on well-documented research in 26 European countries with a population of over 30 million, was presented by CAIRNCROSS [6], [7]. Constructing the index for the air pollution forecast system in Cape Town (RPA), he used the relative risk factors of daily mortality attributed to the increase in the concentration of main pollutants by 10 μg/m^3. The selection of the total mortality rate as the criterion of health risk resulted from the fact that from among the data published by WHO this was the only relative risk factor available for all pollutants and averaging times.

2. METHOD OF CALCULATING *API* INDEX

The modified version of *API* index, proposed by Cairncross, is being discussed. It was assumed that the priority pollutant was PM10. Table 1 presents the WHO relative risk factors in total daily mortality per 10 μg/m^3 increase in pollutant concentration [8]. The relative risk for CO comes from SCHWARTZ'S works [9]. The *API* is calculated for 24-h average concentration of PM10 or PM2.5, for 24-h average concentration of SO_2, for the daily 8-h or 1-h maximum concentration of O_3, for the daily 1-h maximum concentration of NO_2 and for the daily 8-h maximum concentration of CO.

The total risk for simultaneous short-term exposure to several air pollutants is the sum of risk attributed to each pollutant:

$$(RR-1)_{\text{tot.}} = \sum_i [(RR_i - 1)], \tag{1}$$

where:

RR – relative risk,

i = 1, 2, ..., 5 – the subsequent pollutant number.

Table 1

Relative risk *RR* of total daily mortality per 10 μg/m^3 increase in pollutant concentration (for CO – per 10 mg/m^3)

Incidence per 100000	PM10 24-h average	PM2.5 24-h average	SO_2 24-h average	O_3 8-h maximum	O_3 1-h maximum	NO_2 1-h maximum	CO 8-h maximum
	RR (lower–upper limit of 95% confidence interval)						
1013	1.0074 (1.0062–1.0086)	1.015 (1.011–1.019)	1.004 (1.003–1.0048)	1.0051 (1.00023–1.0078)	1.0046 (1.0028–1.0066)	1.003 (1.0018–1.0034)	1.04 –

The overall *API* index is the sum of five sub-indices *PSI*:

$$API = \sum_i PSI_i = \sum_i a_i \cdot C_i \,, \tag{2}$$

where:

a_i – the proportionality coefficient for *i* of this pollutant,

C_i – the concentration *i* of this pollutant.

Table 2

RR levels and breakpoint concentrations (average values) in subsequent *PSI* classes

RR	*PSI* class	PM10 24h (μg/m^3)	PM2.5 24h (μg/m^3)	SO_2 24h (μg/m^3)	O_3 8h (μg/m^3)	O_3 1h (μg/m^3)	NO_2 1h (μg/m^3)	CO 8h (mg/m^3)
1	0	**0**	0	0	0	0	0	0
1.0148	1	**20**	9.9	37.0	29.0	32.2	49.3	3.7
1.0296	2	**40**	19.7	74.0	58.0	64.3	98.7	7.4
1.0444	3	**60**	29.6	111.0	87.1	96.5	148.0	11.1
1.0592	4	**80**	39.5	148.0	116.1	128.7	197.3	14.8
1.0740	5	**100**	49.3	185.0	145.1	160.9	246.7	18.5
1.0888	6	**120**	59.2	222.0	174.1	193.0	296.0	22.2
1.1036	7	**140**	69.1	259.0	203.1	225.2	345.3	25.9
1.1184	8	**160**	78.9	296.0	232.2	257.4	394.7	29.6
1.1332	9	**180**	88.8	333.0	261.2	289.6	444.0	33.3
>1.1480	10+	**>200**	>98.7	>370.0	>290.2	>321.7	>493.3	>37.0

There were assumed 11 classes of air quality. Each class was associated with the relative risk of the total daily mortality being proportional to RR_i per ΔC_i = 10 μg/m^3. The index 0 was attributed to the concentration C_i = 0 μg/m^3 and the unit relative risk

RR = 1. The index 1 was attributed to the non-zero concentrations (20 μg/m^3 for PM10, 9.9 μg/m^3 for PM2.5, 37 μg/m^3 for SO_2, etc.) and the relative risk RR = 1.0148 (table 2). The index 2 was attributed to RR = 1.0296, etc., every ΔRR = 0.0148. The index 10+ was attributed to RR > 1.148. The RR values in the first column of table 2 and the concentrations attributed to the subsequent classes are the average values, representing the variability range. Class 10+ is an exception, which is of an open nature, i.e. it includes the concentrations attributed to $PSI_i > 9$ and the RR values higher than those for the class 9. Thanks to such an intervention the analysis of the cases of extremely high *PSI*/*API* is possible. In order to attribute each RR range to the appropriate number representing the air quality class, it was assumed that PM10 is the priority pollutant. The air quality classes and the relevant RR values were determined in terms of the PM10 concentration. The breakpoint concentrations for the remaining pollutants were calculated proportionally to the individual levels of the relative risk. The limit 24-h PM10 concentration of 50 μg/m^3 constituted the bottom breakpoint of class 3. The breakpoint concentrations for the remaining classes of PM10 were calculated proportionally. The value of the proportionality coefficient a_i = 0.05 for PM10 was calculated according to (2), assuming PSI_i = 3 for C_i = 60 μg/m^3. The values of the remaining coefficients a_i were calculated in the similar way:

PM2.5, a_i = 0.10135; 8h, O_3, a_i = 0.03446; NO_2, a_i = 0.02027,
SO_2, a_i = 0.02703; 1h, O_3, a_i = 0.03108; CO, a_i = 0.27027.

3. RESULTS OF AIR-QUALITY CLASSIFICATION ACCORDING TO *API* FORMULA

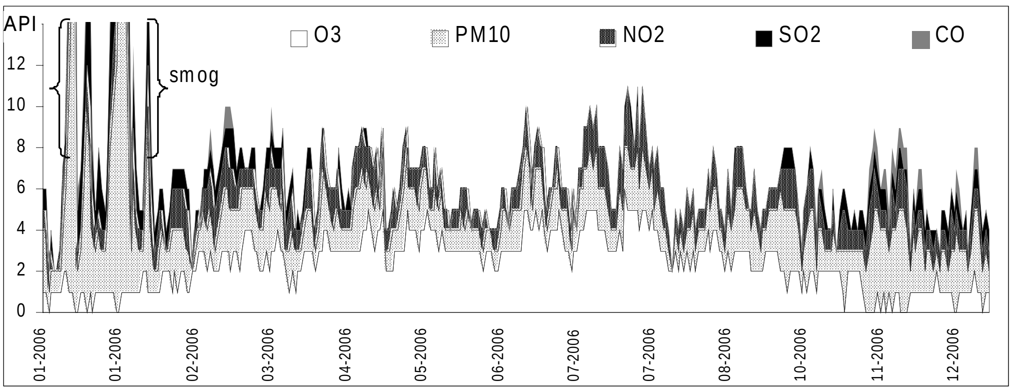
Table 3 presents the sub-indices *PSI* for PM10 and O_3 (8-h) concentrations and the overall *API* index calculated for PM10, SO_2, O_3 (8-h), NO_2 and CO concentrations for 2006 data taken from the air monitoring station in Dąbrowa Górnicza. The results of measurements were made available by the Regional Inspectorate of Environmental Protection (WIOŚ) in Katowice. The *API* chart for the subsequent days of 2006 with the indicated *PSI* proportion is shown in the figure. At the beginning of 2006 extremely high values of *API* were observed, reaching up to 32 (smog episode). The maximum *PSI* values for PM10 and PM2.5 amounted, respectively, to 18 and 23 during this period.

Analyzing the values listed in table 3, an important difference can be observed between the classification of the individual pollutant concentration and the classification of the general state of air pollution. In the case of *PSI*, only for PM10 (as for PM2.5 and SO_2) as much as several per cent of days were observed throughout the year that represented classes 7, 8, 9 and 10+. In the case of *API*, they reached almost 50%. The relatively high proportion of days attributed to class 10+ was due to a winter smog at the beginning of 2006. Generally, one should anticipate more equal distribution of *API* in the classes from 7 to 10+. The pollutant responsible for high values of *AQI* during warmer half of the year is O_3, and in colder one – PM10. The proportion of NO_2 is evenly distributed during the year, and its significance – smaller than those of O_3 and PM10. The input of SO_2 and CO is the weakest. The concentration of these pollutants are high only in winter season. Taking into consideration the marginal proportion of *PSI* for CO at traffic stations [10] and the lack of problems with exceeding the permissible concentration, it seems that excluding CO from the formula for *API* index will not bring about the essential changes of the *API* value. Despite assuming mild criteria of *PSI* classification, in the analyzed sequence of data any single case was not observed, creating the minimum risk (<3%) of the mortality increase resulting from the increase in the concentration of all the pollutants considered.

Table 3

PSI sub-index and overall *API* index for data on pollutant concentration in Dąbrowa Górnicza for year 2006 – percentage participation during the year

RR	*PSI/AQI* class	*PSI* for PM10			*PSI* for O_3 (8-h)			*API*		
		Percentage [%]								
		Summer	Winter	2006	Summer	Winter	2006	Summer	Winter	2006
1	0	1.1	0.5	0.8	0.0	11.5	5.8	0.0	0.0	0.0
1.0148	1	40.4	26.4	33.4	0.5	45.1	22.7	0.0	0.0	0.0
1.0296	2	44.8	33.5	39.2	18.6	30.8	24.7	0.6	2.5	1.5
1.0444	3	13.1	21.4	17.3	48.6	10.4	29.6	0.0	3.8	1.9
1.0592	4	0.5	7.7	4.1	20.8	2.2	11.5	11.6	12.5	12.0
1.0740	5	0.0	2.7	1.4	10.9	0.0	5.5	20.7	18.1	19.4
1.0888	6	0.0	0.5	0.3	0.5	0.0	0.3	22.6	13.8	18.2
1.1036	7	0.0	1.1	0.5	0.0	0.0	0.0	13.4	16.3	14.8
1.1184	8	0.0	0.0	0.0	0.0	0.0	0.0	19.5	15.0	17.3
1.1332	9	0.0	1.1	0.5	0.0	0.0	0.0	6.7	5.0	5.9
>1.1480	10+	0.0	4.9	2.5	0.0	0.0	0.0	4.9	13.1	9.0



Overall *API* index and participation of *PSI* sub-indices. Dąbrowa Górnicza, 2006

4. CONCLUSIONS

The proposal for modifying the *API* index was presented in the study. The additive *API* formula captures the summing effects of the pollutants that appear simultaneously, which was impossible so far. The *API* index better mimics air pollution than traditional formulas, referring to the standards of air quality. *API* formula relates directly to health outcomes produced by exposure to air pollutants through using the WHO relative risk factors of total daily mortality following the increase in pollutants concentration. One should be aware that this is still the simplified description, which does not allow one to observe, e.g., any synergistic effects. The *API* formula is simplified by the assumption that the proportional changes of *RR* per $\Delta C_i = 10\ \mu g/m^3$ occur in the entire range of concentration. Removing these limitations will be possible thanks to the relevant epidemiological studies.

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KLASYFIKACJA JAKOŚCI POWIETRZA NA PODSTAWIE WSKAŹNIKÓW WZGLĘDNEGO RYZYKA WZROSTU UMIERALNOŚCI

Zaprezentowano zmodyfikowaną formułę indeksu jakości powietrza, opartą na koncepcji *API* według Cairncrossa (system DAPPS dla Cape Town, RPA), umożliwiającą ocenę sumujących się skutków krótkookresowej ekspozycji na główne zanieczyszczenia powietrza. Indeks *API* nawiązuje wprost do ryzyka zdrowotnego przez wykorzystanie wskaźników dobowego ryzyka wzrostu umieralności ogólnej. Na przykładzie danych z 2006 r. ze stacji monitoringu w Dąbrowie Górniczej (miejskie tło zanieczyszczeń) przedstawiono wyniki klasyfikacji jakości powietrza z użyciem zmodyfikowanego indeksu *API*.