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AIR QUALITY INDEX AND ITS SIGNIFICANCE IN ENVIRONMENTAL HEALTH RISK COMMUNICATION

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Abstract: Air Quality Index (AQI) is a standardized summary measure of ambient air quality used to express the level of health risk related to particulate and gaseous air pollution. The index, first introduced by US EPA in 1998 classified ambient air quality according to concentrations of such principal air pollutants as PM_{10}, $PM_{2.5}$, ozone, SO_2, NO_2 and CO. Subsequently similar, index-based approach to express health risk was developed in France, Great Britain and Germany. No such environmental warning system exists in Poland, although some test-trials took place in Katowice area and the city of Gdańsk. However, the operational value of AQI under environmental circumstances in Poland remains unknown. The aim of the study was to examine current air pollution levels in Katowice area and to confront AQI categories with local air quality, also in terms of health impact on the population as expressed by daily total and specific mortality. The data on daily average PM_{10} and sulphur dioxide concentrations available in regional network (PIOŚ in Katowice) and data on daily number of total deaths and deaths due to cardiorespiratory diseases from the Central Statistical Office in Warsaw were collected. The data covered the period 2001–2002. The percentage of days with individual Air Quality Index, created by American, French, British and German method of indexation was calculated. Then, the relationship between values of air quality indexes and daily total and specific mortality according to Spearman correlation coefficients was assessed. Finally, the obtained results were verified according to ANOVA Kruskal-Wallis test. The obtained results suggest significant discrepancy in the range of air quality categories depending on applied system of classification. Percentage of days with "unhealthy" air quality (in the period 2001–2002) was running from 0.1% (American method of indexation) to 11.2% (British method) and usually referred to winter season. Statistically significant Spearman correlation coefficients were obtained for the relationship between air quality and total number of deaths, as well as the number of deaths due to cardiovascular and respiratory diseases in elderly population (aged 65 and more). The observed values of correlation coefficients are very low and do not exceed value 0.2 for each chosen method of indexation.

BACKGROUND

The impact of ambient air pollution on human health has been subject to many epidemiological investigations performed worldwide and targeting morbidity and mortality, both total and specific mostly due to respiratory and circulatory diseases. The accumulated epidemiologic evidence provided scientific background for regular assessment of air pollution-related health risk, summarized in the reports published under the auspices of World Health Organization [15]. A wide spectrum of health risk estimates and their presentation are commonly used by public health professionals; however their meaning is less clear to the public, more and more interested in environmental health hazards. A need to communicate the results and inform the public about potential health impacts of the measured and/or projected ambient air pollution levels prompted an effort to develop easily understood information, of every-day use by the public, including administrative authorities [6, 13]. The concept was addressed as early as in 1970 at the European level and was followed by initiatives taken by the Environmental Protection Agency in the USA in 1998 [2, 5]. As a result summary index, known as the Air Quality Index (AQI) was introduced in order to express an increasing health risk to the public in response to increasing ambient air pollution, on a daily basis. The construction of AQI allows for distinction between "good" and "bad" air quality.

The Air Quality Index developed in the USA is based on the combined effects of five criteria pollutants: suspended particulate matter – aerodynamic diameter below 10 and 2.5 μm (PM_{10}, $PM_{2.5}$), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and nitrogen dioxide (NO_2) [1]. Concentrations of the pollutants are recorded by automatic air monitoring stations permitting prompt data analysis and transformation of the readings into the AQI scale. The range of AQI values includes seven categories grouped into "good", "moderate" and "dangerous" air quality zones [1]. The "good" air quality zone is defined if the AQI is in the range of 0 to 50. The "moderate" air quality zone is defined if the AQI is between 51 and 100. The "dangerous" air quality zone is defined if the AQI exceeds 100. A similar three-level approach has been adopted in the European countries. Table 1 shows the cut-of values for the specific air quality zones used in France, Great Britain and Germany, compared to the US standards [12, 18–19]. In addition to the between-country differences in the decisive cut-of values of air pollution the country-specific AQIs differ in the internal composition, as shown in Table 2 [12, 18–19]. Moreover, in each country the AQI is calculated on the daily basis.

The presentation of AQIs implies their practical application, both in environmental health risk communication to the public (via media) and as an evidence-based support for preventive measures. Because of its simplicity the AQI serves as a convenient early warning tool. No such environmental warning system exists in Poland, although some test-trials took place in Katowice area and the city of Gdańsk [4, 16]. However, the operational value of AQI under environmental circumstances in Poland remains unknown. Because of poor ambient air quality in our country it is essential to examine the potential for AQI application and to explore the system's functioning given ambient air quality in Poland. For a number of reasons relevant findings could be provided by a pilot study implemented under the "worst case scenario", in terms of ambient air pollution. Hence, the aim of the study was to examine current air pollution levels in Katowice area and to confront local air quality with AQI categories, also in terms of health impact on the population as expressed by daily total and specific (cardiovascular and respiratory) mortality.

MATERIAL AND METHODS

Data concerning ambient air pollution, such as particulate matter PM10 and sulphur dioxide, and meteorological conditions were obtained from regional network providing on-line measurements by the State Environmental Agency in Silesia voivodeship. There were calculated as 24-hour area averages and applied to measurements in 14 regional stations. Mortality data (total and specific mortality) were obtained from the register at the Central Statistical Office in Warsaw. The records were analyzed according to the classification scheme of the International Classification of Diseases – 10^{th} Edition (ICD-10) [11] and included the number of daily deaths in population living in the urban area of Katowice from January 01 to December 31 in the period 2001–2002. Daily mortality was arranged in three categories: all deaths, deaths due to cardiovascular causes (ICD-10 codes: I00-I99) and deaths due to respiratory causes (ICD-10 codes: J00-J99). Moreover, analysis was taken for the two aged groups: inhabitants aged 0–64 years and aged 65 and more. The percentage of days with selected AQI categories was calculated according to available method (American, French, British and German), but established way of indexation refers to only 24-hourly PM10 concentrations. Next, mean value of daily number of deaths characteristic for days with particular categories quality of air, expressed by 33^{th} and 66^{th} percentile of PM10 concentration or specific AQI value was calculated. The association between air quality and daily number of deaths was calculated by ANOVA Kruskal-Wallis procedure. Moreover, the relationship between daily number of deaths and value of AQI was estimated by means of Spearman correlation analysis. Finally, the obtained results were verified by ANOVA Kruskal-Wallis procedure. Interpretation of statistical significance of the results was based on the criterion $p < 0.05$. Statistica 7.1 statistical software was used for all calculations.

RESULTS

Values of daily particulate matter (PM10) and sulphur dioxide (SO_2) concentrations measured in the urban area of Katowice, in the study period (year 2001–2002), are presented in Table 3. A mean value was below the acceptable limit value for both sorts of pollution, but maximum concentrations observed exceeded the established norms only in winter time.

Percentage of days with selected value of AQI calculated for PM10 concentrations, defined such as "dangerous air quality", depends on chosen indexation method and amounted from 0.1% (American method – AQI in the range of 4–7) and 6.1% (German – AQI 6, and French method – AQI in the range of 8–10) to over 11% (British method – AQI in the range of 7–10) and usually concerned winter season.

The observed number of total deaths, deaths due to cardiovascular and respiratory diseases, their average values and number of deaths during days with low, medium or high concentration of particulate matter (PM10) are presented in the Table 4. Most of deaths (about 47% out of 39 222 cases) concerned deaths due to cardiovascular diseases, and most of them appeared in the older population (people aged 65 year or more). Deaths due to respiratory diseases represent nearly 4.1% of the total mortality in the study period, but it is significant that most of them (78.2%) concerned the elderly. Moreover, it was observed that the number of total deaths and deaths due to cardiorespiratory diseases in total and old population depends on a chosen level of PM concentration, defined by the values

Table 1. Comparison of the definition of three categories of ambient air quality ("good", "moderate", "dangerous") used in Air Quality Indices in the USA, France, Great Britain and Germany – example for 24 hour PM10 concentration

Category of air quality	Cut-off values for daily PM10 concentration [μg/m³]			
	USA	France	Great Britain	Germany
Good	0–54	0–39	0–49	0–34
Moderate	55–154	40–79	50–74	35–99
Dangerous	155 and more	80 and more	75 and more	100 and more

Table 2. Composition of Air Quality Index in selected countries

AQI	USA	France	Great Britain	Germany
1	good air quality	good air quality	good air quality	good air quality
2	moderate air quality	good air quality	good air quality	good air quality
3	moderate air quality	good air quality	good air quality	good air quality
4	dangerous air quality	good air quality	moderate air quality	moderate air quality
5	dangerous air quality	moderate air quality	moderate air quality	moderate air quality
6	dangerous air quality	moderate air quality	moderate air quality	dangerous air quality
7	dangerous air quality	moderate air quality	dangerous air quality	
8		dangerous air quality	dangerous air quality	
9		dangerous air quality	dangerous air quality	
10		dangerous air quality	dangerous air quality	

Table 3. Daily means concentrations of PM10 and SO_2 in ambient air in urban area of Katowice, in the period 2001–2002

	Sulphur dioxide SO_2 [μg/m³]	Particulate matter PM10 [μg/m³]
Mean value ± SD	35.21 ± 24.18	48.98 ± 34.26
Median	27.10	39.45
Minimum	10.50	11.20
Maximum	239.80	421.30
33.3 percentile	21.90	31.80
66.6 percentile	36.50	49.30

Table 4. Total and daily number of deaths in the Urban Area of Katowice, in the study period 2001–2002

Deaths due to	Age	Total number of deaths	Average ± SD	Number of deaths during days with selected concentrations of PM10		
				low (< 31,8 μg/m³)	medium (31,8–49,3 μg/m³)	high (> 49,3μg/m³)
Cardiovascular diseases	0–64 years	4391	6.0 ± 2.4	6.2 ± 2,4	5.7 ± 2.3	6.0 ± 2.5
	65 and more	14065	19.2 ± 4.8	18.7 ± 4.4	18.8 ± 4.7	20.2 ± 5.0
	total	18456	25.2 ± 5.5	24.9 ± 5.3	24.6 ± 5.4	26.2 ± 5.8
Respiratory diseases	0–64 years	348	0.4 ± 0.7	0.4 ± 0.7	0.4 ± 0.6	0.5 ± 0.7
	65 and more	1246	1.7 ± 1.3	1.5 ± 1.2	1.7 ± 1.4	1.8 ± 1.4
	total	1594	2.1 ± 1.6	1.9 ± 1.4	2.1 ± 1.6	2.4 ± 1.6
Total	0–64 years	14220	19.4 ± 4.7	19.4 ± 4.8	19.2 ± 4.6	19.6 ± 4.6
	65 and more	25002	34.2 ± 6.3	33.1 ± 5.8	34.2 ± 6.5	35.5 ± 6.4
	total	39222	53.7 ± 8.2	52.6 ± 8.3	53.4 ± 8.4	55.1 ± 8.0

Table 5. Total and daily number of deaths in the Urban Area of Katowice, in the study period 2001–2002

Deaths due to	Age	Number of deaths during days with selected AQI (mean value ± SD)											
		Great Britain			France			USA			Germany		
		g	m	d	g	m	d	g	m	d	g	m	d
Cardio-vascular diseases	< 65	6.0 ± 2.4	5.7 ± 2.3	6.3 ± 2.8	6.0 ± 2.4	5.9 ± 2.4	6.2 ± 2.8	5.9 ± 2.4	6.1 ± 2.6	9.0 ± 0	6.1 ± 2.4	5.9 ± 2.5	6.0 ±2.7
	65+	18.8 ± 4.6	19.9 ± 4.7	20.6 ± 5.3	18.8 ± 4.6	19.5 ± 4.9	20.5 ± 5.2	18.8 ± 4.6	20.3 ± 5.0	25.0 ± 0	18.7 ± 4.6	19.5 ± 4.9	20.7 ± 5.1
	total	24.8 ± 5.4	25.6 ± 5.3	26.9 ± 6.1	24.8 ± 5.4	25.5 ± 5.6	26.7 ± 5.9	24.8 ± 5.4	26.4 ± 5.7	34.0 ± 0	24.9 ± 5.5	25.4 ± 5.5	26.7 ± 5.8
Respiratory diseases	< 65	0.4 ± 0.7	0.5 ± 0.8	0.6 ± 0.8	0.4 ± 0.7	0.5 ± 0.7	0.6 ± 0.8	0.4 ± 0.7	0.5 ± 0.7	1.0 ± 0	0.4 ± 0.7	0.5 ± 0.7	0.7 ± 0.9
	65+	1.6 ± 1.3	1.7 ± 1.4	2.0 ± 1.5	1.6 ± 1.3	1.8 ± 1.4	2.0 ± 1.4	1.6 ± 1.3	1.9 ± 1.4	2.0 ± 0	1.6 ± 1.3	1.8 ± 1.4	2.0 ± 1.5
	total	2.1 ± 1.6	2.3 ± 1.5	2.6 ± 1.7	2.0 ± 1.6	2.3 ± 1.6	2.6 ± 1.6	2.1 ± 1.5	2.5 ± 1.6	3.0 ± 0	2.0 ± 1.5	2.3 ± 1.6	2.7 ± 1.7
Total	< 65	19.4 ± 4.7	19.5 ± 4.8	19.7 ± 4.5	19.3 ± 4.7	19.5 ± 4.8	19.9 ± 4.3	19.4 ± 4.8	19.6 ± 4.5	29 ± 0	19.3 ± 4.9	19.5 ± 4.6	20.4 ± 4.4
	65+	33.6 ± 6.2	34.9 ± 6.3	36.0 ± 6.4	33.4 ± 6.2	34.8 ± 6.3	36.1 ± 6.7	33.8 ± 6.3	35.4 ± 6.3	40.0 ± 0	33.4 ± 6.2	34.6 ± 6.4	36.7 ± 5.6
	total	53.0 ± 8.3	54.5 ± 8.0	55.9 ± 7.9	52.7 ± 8.5	54.3 ± 7.8	56.1 ± 7.9	53.2 ± 8.5	55.0 ± 7.6	69.0 ± 0	52.7 ± 8.8	54.1 ± 7.8	57.1 ± 7.7

g – good, m – moderate, d – dangerous

Table 6. Spearman correlation coefficients for relationship between daily count of deaths and air quality index by different methods of indexation, p value in brackets

Daily mortality	Population aged	AQI Great Britain	AQI France	AQI USA	AQI Germany
Cardiorespiratory diseases	0–64	0.00 (NS)	0.01 (NS)	0.04 (NS)	0.00 (NS)
	65+	0.15 ($p < 0.05$)	0.15 ($p < 0.05$)	0.16 ($p < 0.05$)	0.14 ($p < 0.05$)
	total	0.13 ($p < 0.05$)	0.13 ($p < 0.05$)	0.16 ($p < 0.05$)	0.12 ($p < 0.05$)
Cardiovascular diseases	0–64	-0.02 (NS)	-0.01(NS)	0.03 (NS)	-0.01(NS)
	65+	0.13 ($p < 0.05$)	0.14 ($p < 0.05$)	0.14 ($p < 0.05$)	0.13 ($p < 0.05$)
	total	0.11 ($p < 0.05$)	0.11 ($p < 0.05$)	0.14 ($p < 0.05$)	0.10 ($p < 0.05$)
Respiratory diseases	0–64	0.07(NS)	0.08 (NS)	0.08 (NS)	0.07 (NS)
	65+	0.10 ($p < 0.05$)	0.11 ($p < 0.05$)	0.10 ($p < 0.05$)	0.10 ($p < 0.05$)
	total	0.12 ($p < 0.05$)	0.13 ($p < 0.05$)	0.13 ($p < 0.05$)	0.12 ($p < 0.05$)
Total number of deaths	0–64	0.03 (NS)	0.03 (NS)	0.04 (NS)	0.04 (NS)
	65+	0.17 ($p < 0.05$)	0.17 ($p < 0.05$)	0.13 ($p < 0.05$)	0.16 ($p < 0.05$)
	total	0.15 ($p < 0.05$)	0.15 ($p < 0.05$)	0.11 ($p < 0.05$)	0.14 ($p < 0.05$)

NS – not statistically significant

Table 7. Results of ANOVA Kruskal-Wallis and median procedure (p values) in relationship between AQI and daily mortality, urban area of Katowice in the period 2001–2002

Mortality	Population aged	AQI Great Britain		AQI France		AQI USA		AQI Germany	
		K-W	M	K-W	M	K-W	M	K-W	M
Cardio-respiratory diseases	total	0.0009	0.009	0.0005	0.01	0.0001	0.0009	0.004	0.01
	0–64	0.1	0.3	0.07	0.1	0.3	0.5	0.4	0.5
	65+	0.001	0.007	0.0007	0.001	0.0001	0.0001	0.001	0.001
Total number of deaths	total	0.004	0.02	0.004	0.01	0.004	0.03	0.0001	0.01
	0–64	0.8	0.7	0.7	0.8	0.1	0.2	0.5	0.4
	65+	0.001	0.0009	0.0005	0.0003	0.002	0.0005	0.0007	0.001

K-W – Kruskal-Wallis procedure, M – median test

of 33.33 and 66.66 percentile. The highest mortality concerned days with high level of air pollution, exceeding the concentration of 49.3 $\mu g/m^3$.

Moreover, mean value was calculated of daily total and specific mortality characteristic for days with particular AQI defined as: good, moderate and dangerous category of air quality, determined by particular methods of indexation. It was observed that the highest mortality concerned the days with dangerous quality of air. Detailed results are presented in Table 5. The association between mortality and quality of air was similar for German, British and French method of indexation, but finally the obtained results confirm that the highest mortality concerned the days with dangerous quality of air, and the lowest concerned the days with good quality of air. The observed variability was statistically significant in each of AQI categories.

The relationship between daily number of deaths, separately for total and specific mortality, and value of particular AQI was estimated by means of Spearman correlation analysis. The obtained results are presented in Table 6 and confirm existence of statistically significant correlation for each chosen air quality index and daily count of deaths in total and elderly population, although values of correlation coefficients were below 0.20. It was observed that particular values of correlation coefficient were similar in each applied method of AQI indexation. It was documented that the higher level of AQI is associated with the increase of daily mortality.

Finally, the obtained results were verified by ANOVA Kruskal-Wallis procedure and additionally by median test. Table 7 presents particularly data (statistically significant expressed by "p" value) in both tests for separate air quality indexes. The results suggest that the difference between medians of compared groups is not statistically significant only in population aged 0–64 years.

DISCUSSION

The obtained results suggest disagreement on the range of air quality according to selected classification method. Percentage of days with "unhealthy" air quality (in the period 2001–2002) was between 0.1% (American method of indexation) and 11.2% (British method). The frequencies of days with air quality dangerous for health (PM10 concentrations) calculated by French and German AQI were similar and amounted nearly 6%. Moreover, it was observed that the highest number of daily mortality was characteristic for days with the highest level of PM10 concentration expressed by percentile value of PM10 concentration or by AQI value. The association between mortality and quality of air was similar for German, British and French method of indexation, the course of relationship for American AQI was quite different, but finally the highest mortality was assigned to dangerous air quality. We noted statistically significant relationship between daily number of total deaths and deaths due to cardiovascular/respiratory diseases and air quality index in the elderly (population aged 65+ years) and in total population. These results confirm the fact that older people are the most sensitive group of population in environmental health and our data are comparable with well-known published data [3, 8–10, 14].

According to poor ambient air quality in Silesia region, especially during winter time, it is essential to inform inhabitants about environmental health hazard. Confrontation data of local air quality with AQI categories and with daily total and specific (cardiovascular and respiratory) mortality confirm the fact that British and French methods of AQI indexation are the best way to inform about risk in Poland. Probably, similar climate conditions and specific of air pollution are comparable in all described countries, so the association between air quality index and health effect is similar too.

Despite existence of very interesting handbooks prepared for older people [7, 17] the information is not clear enough and available to protect a person with cardiovascular or respiratory problems from undesirable health effects. It is necessary to disclose the knowledge about air quality index and its association with health effect. Very important source of this information are medical doctors, especially general practitioners. Moreover, well known websites or regional TV channels are very useful sources to transmit important information about environmental health risk.

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INDEKS JAKOŚCI POWIETRZA I JEGO ZNACZENIE DLA KOMUNIKOWANIA ŚRODOWISKOWEGO RYZYKA ZDROWOTNEGO

Indeks jakości powietrza (AQI) jest wskaźnikiem określającym jakość powietrza atmosferycznego i jednocześnie wskazującym potencjalne ryzyko zdrowotne ponoszone przez populację wskutek narażenia na standardowo mierzone stężenia zanieczyszczeń pyłowych i gazowych w danym regionie. Po raz pierwszy został użyty przez US EPA w 1998 r. i klasyfikował jakość powietrza atmosferycznego w oparciu o stężenia podstawowych zanieczyszczeń: PM_{10}, $PM_{2.5}$, ozonu, SO_2, NO_2 oraz CO. Podobne wskaźniki, oparte na danych regionalnych opracowano również we Francji, Wielkiej Brytanii i Niemczech. Właściwie w naszym kraju nie funkcjonuje spójny system komunikowania ryzyka zdrowotnego, który byłby oparty na własnym indeksie jakości powietrza, chociaż pewne próby podejmowane są w Katowicach i Gdańsku. Celem prezentowanej pracy była ocena jakości powietrza atmosferycznego w Katowicach na podstawie przyjętych kategorii AQI oraz porównanie uzyskanych danych z danymi opisującymi potencjalne ryzyko zdrowotnego wyrażone w postaci dobowej umieralności całkowitej lub specyficznej. Zebrano dane dotyczące średnich dobowych stężeń pyłu PM10 oraz dwutlenku siarki dostępne w ramach regionalnego monitoringu środowiska (PIOŚ w Kato-

wicach) oraz dane dotyczące dobowej liczby zgonów ogółem i zgonów z powodu chorób układu oddechowego i krążenia pochodzące z bazy Głównego Urzędu Statystycznego w Warszawie. Wszystkie dane dotyczyły okresu 2001–2002. Obliczono odsetki dni z właściwym dla nich indeksem jakości powietrza stosując amerykański, francuski, brytyjski i niemiecki sposób indeksowania. Następnie oceniono zależność pomiędzy przyjętą kategorią jakości powietrza a dobową umieralnością ogólną i specyficzną z zastosowaniem współczynników korelacji Spearmana. Ostatecznie uzyskane wyniki zweryfikowano przy użyciu testu ANOVA Kruskal-Wallis. Uzyskane wyniki sugerują występowanie istotnego zróżnicowania w zakresie kategorii jakości powietrza atmosferycznego, zależnie od przyjętego sposobu klasyfikacji. Procent dni z tzw. „niezdrową" jakością powietrza kształtował się w badanym okresie (2001–2002) w zakresie od 0,1% (amerykański sposób indeksowania) do 11,2% (brytyjski sposób indeksowania) i zazwyczaj kategoria dotyczyła okresu zimy. Statystycznie znamienne wartości współczynników korelacji Spearmana uzyskano jedynie dla zależności pomiędzy jakością powietrza a dobową liczbą zgonów ogółem oraz zgonów z powodu chorób układu oddechowego i krążenia w grupie osób po 65 roku życia. Jednakże zaobserwowane wartości współczynników były niewielkie i nie przekraczały wartości 0,2 dla każdej z przyjętych metod klasyfikacji.