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OVERALL HUMAN MORTALITY AND MORBIDITY DUE TO EXPOSURE TO AIR POLLUTION

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Abstract
Objectives: Concentrations of particulate matter that contains particles with diameter ≤ 10 mm (PM_{10}) and diameter ≤ 2.5 mm ($PM_{2.5}$) as well as nitrogen dioxide (NO_2) have considerable impact on human mortality, especially in the cases when cardiovascular or respiratory causes are attributed. Additionally, they affect morbidity. An estimation of human mortality and morbidity due to the increased concentrations of PM_{10}, $PM_{2.5}$ and NO_2 between the years 2005–2013 was performed for the city of Kraków, Poland. For this purpose the Air Quality Health Impact Assessment Tool (AirQ) software was successfully applied. **Material and Methods:** The Air Quality Health Impact Assessment Tool was used for the calculation of the total, cardiovascular and respiratory mortality as well as hospital admissions related to cardiovascular and respiratory diseases. Data on concentrations of PM_{10}, $PM_{2.5}$ and NO_2, which was obtained from the website of the Voivodeship Inspectorate for Environmental Protection (WIOS) in Kraków, was used in this study. **Results:** Total mortality due to exposure to PM_{10} in 2005 was found to be 41 deaths per 100 000 and dropped to 30 deaths per 100 000 in 2013. Cardiovascular mortality was 2 times lower than the total mortality. However, hospital admissions due to respiratory diseases were more than an order of magnitude higher than the respiratory mortality. **Conclusions:** The calculated total mortality due to $PM_{2.5}$ was higher than that due to PM_{10}. Air pollution was determined to have a significant effect on human health. The values obtained by the use of the AirQ software for the city of Kraków imply that exposure to polluted air can result in serious health problems.

Key words:
Respiratory diseases, Cardiovascular diseases, Nitrogen dioxide, Health Impact Assessment, HIA, Airborne particulate matter

INTRODUCTION

Even though ambient air pollution is decreasing every year, its level still remains high. The most extensively studied species are: PM_{10} (particulate matter which contains particles with diameter ≤ 10 mm), $PM_{2.5}$ (particulate matter which contains particles with diameter ≤ 2.5 mm) and nitrogen dioxide (NO_2). Concentration of sulfur dioxide (SO_2) remains at a relatively low level compared to that representative of the previous century, following a significant decrease of SO_2 concentration in the air during that period of time. The limit values for pollutants' concentrations can be found in the European Union Directives [1,2]; however, actual numbers in some European cities exceed those values. Such a phenomenon occurs

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mainly during wintertime when heating sources used in residential areas have a significant influence on the concentrations of particulate matter (PM) in the air [3,4].

Ambient air pollution sources mainly include: stationary, industrial and domestic fossil fuel combustion as well as petrol and diesel vehicle emissions [5]. Toxicity of PM strongly depends on its chemical content. Health effects of human exposure to air pollution can be either long or short term, and different pollutants may have significantly different exposure-response characteristics [5].

Particulate matter which contains particles with diameter ≤ 10 mm are "thoratic" particles that can penetrate into the lower respiratory system. Particulate matter which contains particles with diameter ≤ 2.5 mm are "respirable" particles that can penetrate into the gas-exchange region of the lungs [6]. Although individual air pollutants can exert their own specific toxic effects on the respiratory and cardiovascular systems, ozone, nitrogen oxides and suspended particulates all share the common property of being potential oxidants, either through direct effects on lipids and proteins or indirectly, through the activation of intracellural oxidant pathways [6].

Air pollution can cause increasing hospital admissions due to respiratory and cardiovascular diseases, asthma attacks, acute bronchitis and lung function decline. Premature mortality and morbidity may be a result of exposure to polluted air [7–11]. In 2011 long term exposure to $PM_{2.5}$ was responsible for about 458 000 premature deaths in 40 European countries [12]. According to the World Health Organization (WHO) data, air pollution accounts for 800 000 deaths per year around the globe [13]. Likhvar et al. have performed studies presenting future health impacts under alternative assumptions about future emissions and climate across multiple spatial scales for the years 2030 and 2050 [14].

Kraków is located in the Vistula Valley in Southern Poland. It is one of the most polluted cities in Poland. Daily PM_{10} concentrations exceed the limit value provided by the European Union regulations. This effect is especially pronounced during the winter time [15]. The target value for $PM_{2.5}$ concentrations is also exceeded on other numerous occasions [15]. Location of the city in a valley together with its unique climate highly influence the observed level of air pollution [3,4].

The main industrial area is located in the eastern part of the city. It includes ferrous and steel, cement, building and ceramics industries as well as heat and power plants. Combustion, municipal emissions and traffic also have a significant effect on the level of pollution in Kraków. Secondary aerosols are an important source of pollution too, especially in the summer [3,4]. In the case when pollution is so prevalent, it is absolutely necessary to evaluate its influence on the health of the area inhabitants.

In this study, the Air Quality Health Impact Assessment Tool (AirQ) software [16] was employed to determine the dependence of total mortality, respiratory track mortality, cardiovascular mortality as well as hospital admissions due to respiratory track diseases and cardiovascular illnesses, on the exposure to PM_{10}, $PM_{2.5}$, and NO_2 in Kraków, Poland.

MATERIAL AND METHODS

Concentrations of PM_{10}, $PM_{2.5}$ and NO_2 in the air, used to assess the pollutants' influence on human health, were obtained from the website of the Voivodship Inspectorate for Environmental Protection (WIOS) [15]. Concentration data for the time period 2005–2013 was examined for 3 WIOS monitoring stations located in Kraków: an industry based station in Nowa Huta, a station in a residential area in Krowodrza (since 2010 – Kurdwanów) and a traffic-focused station at Krasicki Alley. The results concerning concentrations of PM_{10}, $PM_{2.5}$ and NO_2 obtained from the monitoring stations Krowodrza and Kurdwanów were comparable irrespectively of their different locations. Any missing air pollution data in a specific monitoring station was replaced by an average of the corresponding values for the other monitoring stations.

Estimation of the health impact of air pollution on the population of Kraków was performed by the use of the AirQ software package developed at the WHO Centre for Environment and Health/WHO-ECEH/ Bilthoven Division, Netherlands. The Air Quality Health Impact Assessment Tool is a specialized software, which enables the user to assess potential impact of the exposure to a given air pollutant in a defined urban area during a specified time period on human health. Adverse health effects of specific air pollutants for the above mentioned period were calculated by taking into account the relative risk, mortality and morbidity of a predefined population.

Attributable proportion (AP) is a fraction of the health outcome that can be attributed to the exposure to a specific pollutant of a given population for a defined period of time. This is determined under the assumption that an association between exposure and health outcome exists and no major confounding effects are present.

$$AP = \frac{\sum_c ((RR(c) - 1) \times p(c))}{\sum_c RR(c) \times p(c)} \quad (1)$$

where:

RR(c) – relative risk for the health outcome in category c of the exposure,

p(c) – proportion of the population in category c of the exposure.

Relative risk (RR) for the selected health outcome was derived from the exposure-response function obtained from the WHO default values [5,17].

Assuming a certain baseline frequency of the selected health outcome in the population (I), the rate (or number of cases per population unit) attributed to the exposure in the population (I_E) was calculated as:

$$I_E = I \times AP \quad (2)$$

Detailed calculations can be found in literature [16,18]. To perform relevant calculations in the AirQ software, the following information was used: type of a pollutant, city, year, number of inhabitants, number of stations in which measurements were performed as well as the Air Quality Data including average concentrations together with the number of measurements in a certain range. Additionally, data for the station with the lowest and highest concentration values was inserted in this section. After including a relative risk value and after choosing a health effect of interest, the software carried out calculations resulting in the number of people representing the selected health outcome.

Data from WIOS in Kraków was pre-processed prior to being entered into the AirQ software and it is shown in Tables 1–4.

Table 1 presents different ranges of concentration values for PM_{10} and the number of days in a year during which these numbers were recorded. Table 2 shows the mean values of PM_{10} concentrations for the entire period of the study for all the monitoring stations in the city. Tables 3 and 4 depict data from 2 stations which represented the highest and the lowest values of PM_{10} concentrations. The data shown in Tables 1–4 was entered to the AirQ and defined as starting values. Concentrations of $PM_{2.5}$ and NO_2 were prepared for processing in an identical manner. The relevant numbers are not included in this paper.

Ethics: No clinical trials have been conducted as part of the presented research.

RESULTS AND DISCUSSION

Figures 1–5 show the calculated values for the total mortality (Figure 1), cardiovascular mortality (Figure 2), respiratory mortality (Figure 3), hospital admissions due to cardiovascular diseases (Figure 4) and hospital admissions due to respiratory diseases (Figure 5) attributed to exposure to PM_{10}. The analyses were performed for the inhabitants of Kraków during the 2005–2013 period. The population

Table 1. Days during the year with the concentrations of PM_{10} placed in a given range – entered into the AirQ, Kraków, Poland, in 2005–2013

PM_{10} concentration [µg/m³]	Exposition in subsequent years [days]								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
< 10	0	0	0	0	0	2	3	1	0
10–19	11	7	9	13	9	19	21	27	18
20–29	51	39	57	42	38	43	53	64	87
30–39	59	42	56	64	73	59	70	73	72
40–49	63	50	58	49	60	57	45	55	57
50–59	29	45	38	44	42	36	30	24	26
60–69	29	39	24	43	37	24	19	21	27
70–79	29	23	28	29	28	21	15	15	25
80–89	11	25	11	17	10	17	19	18	9
90–99	22	12	18	12	15	12	17	16	13
100–109	7	16	16	7	11	15	11	10	9
110–119	14	10	10	9	8	10	10	8	5
120–129	8	7	8	8	7	11	12	9	5
130–139	9	9	8	7	7	8	10	2	2
140–149	2	7	6	4	8	5	8	5	1
150–159	6	9	4	8	2	7	7	1	2
160–169	2	3	3	2	3	1	5	2	2
170–179	1	2	3	3	1	3	3	3	3
180–189	3	0	2	0	1	2	1	2	1
190–199	2	3	1	1	2	6	1	1	0
200–249	4	5	5	3	2	2	2	5	1
250–299	1	4	0	0	1	2	3	2	0
300–349	0	3	0	1	0	2	0	2	0
350–399	0	2	0	0	0	1	0	0	0
≥ 400	2	3	0	0	0	0	0	0	0
Total	365	365	365	366	365	365	365	366	365

PM_{10} – particulate matter which contains particles with diameter ≤ 10 mm; AirQ – The Air Quality Health Impact Assessment Tool.

Table 2. The annual, winter and summer mean and max concentrations of PM_{10}, Kraków, Poland, 2005–2013

Year	PM10 concentration [μg/m3]						
	annual		summer		winter		98th percentile
	M	max	M	max	M	max	
2005	67	574	46	209	88	574	192
2006	79	631	50	176	109	631	312
2007	65	310	50	180	79	310	185
2008	63	257	45	164	82	257	170
2009	64	280	46	181	81	280	166
2010	67	398	40	126	98	398	199
2011	65	356	37	105	93	356	177
2012	58	402	35	84	84	402	215
2013	51	253	35	117	67	253	158

PM_{10} – as in Table 1; M – mean; max – maximal value.

Table 3. The data from the monitoring station (Krasiński Alley) presenting the highest concentrations of PM_{10}, Kraków, Poland, 2005–2013

Year	PM10 concentration [μg/m3]						
	annual		summer		winter		98th percentile
	M	max	M	max	M	max	
2005	88	574	60	209	112	574	249
2006	96	631	60	161	134	631	356
2007	81	310	65	180	97	310	214
2008	81	367	58	154	105	367	216
2009	78	280	61	181	95	280	184
2010	79	398	49	126	110	398	214
2011	76	356	45	105	109	356	201
2012	63	402	34	83	107	402	217
2013	60	253	42	117	77	253	178

Abbreviations as in Table 1 and 2.

of Kraków at the time when the research was carried out (in the year 2010) was approximately 756 000. The values were calculated per 100 000 inhabitants and were determined with a 95% confidence level.

Total mortality due to exposure to PM_{10} in 2005 was 41 deaths per 100 000 and dropped to 30.1 deaths in 2013. The attributable proportion was estimated to be 4.04% in 2005 and decreased to 2.97% in 2013. Values of I and RR, which were used in this study, were reported by Sega and Beslic [17,18] and they are in accordance with the WHO epidemiological data. Cardiovascular mortality due to exposure to PM_{10} was 2 times lower

Table 4. The data from the monitoring stations (Krowodrza, Kurdwanów) with the lowest concentrations of PM_{10}, Kraków, Poland, 2005–2013

Year	PM_{10} concentration [µg/m³]						
	annual		summer		winter		98th percentile
	M	max	M	max	M	max	
2005	55	354	38	111	73	354	171
2006	64	311	41	106	90	311	247
2007	56	266	36	143	70	266	177
2008	50	294	35	135	65	294	144
2009	55	250	37	123	74	250	166
2010	51	369	32	74	85	369	198
2011	54	313	30	97	79	313	158
2012	53	335	30	62	76	335	182
2013	46	235	28	95	63	235	153

Abbreviations as in Table 1 and 2.

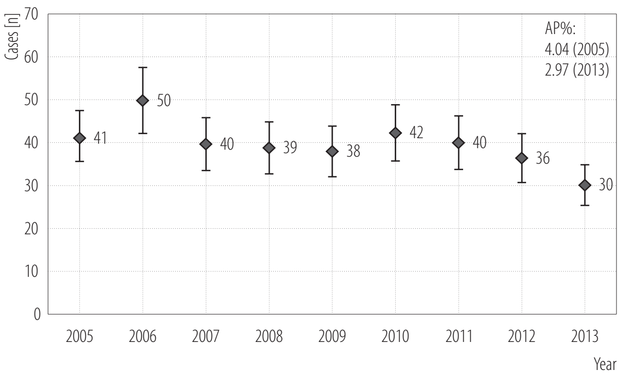

Fig. 1. Total mortality attributed to exposure to PM_{10}, Kraków, Poland, 2005–2013

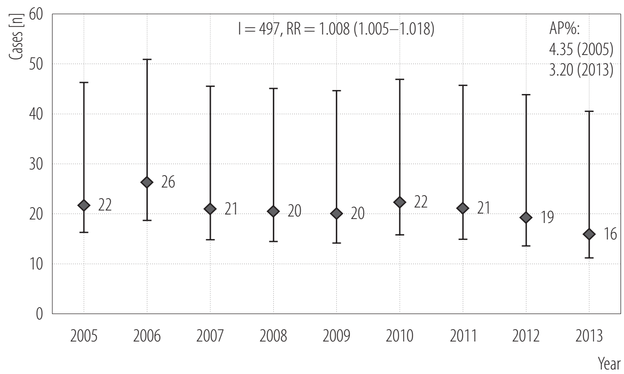

Fig. 2. Cardiovascular mortality attributed to exposure to PM_{10}, Kraków, Poland, 2005–2013

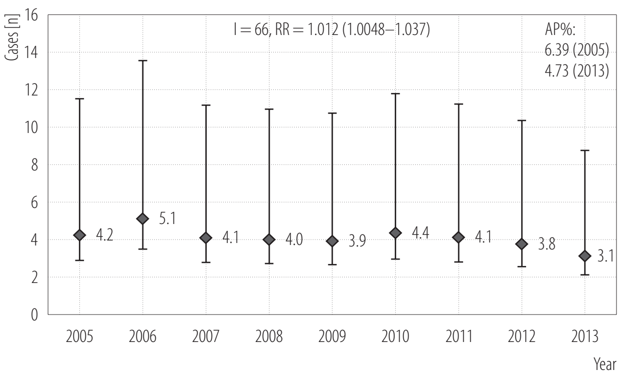

Fig. 3. Respiratory mortality attributed to exposure to PM_{10}, Kraków, Poland, 2005–2013

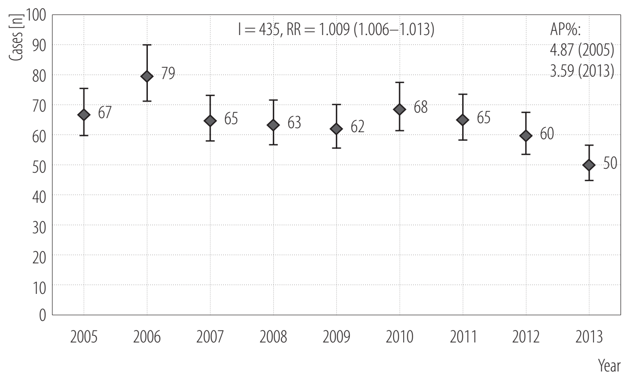

Fig. 4. Hospital admissions – cardiovascular diseases attributed to exposure to PM_{10}, Kraków, Poland, 2005–2013

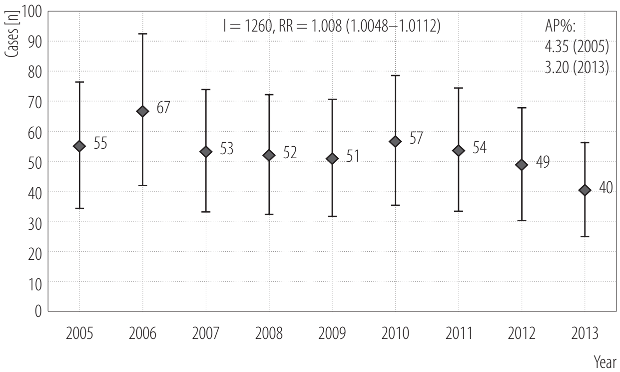

Fig. 5. Hospital admissions – respiratory diseases attributed to exposure to PM_{10}, Kraków, Poland, 2005–2013

than the total mortality. The number of hospital admissions attributed to cardiovascular diseases was 3 times as high as cardiovascular mortality. However, hospital admissions due to respiratory diseases were more than 10 times higher than respiratory mortality. There were 55 and 4.2 cases per 100 000 inhabitants, respectively, in 2005, and 40 and 3.1 cases per 100 000 inhabitants, respectively, in 2013. In the study period, cardiovascular mortality was 5 times higher than respiratory mortality. By contrast, during the investigated time period hospital admissions due to respiratory and cardiovascular diseases were approximately equal.

Figure 6 shows the determined total mortality attributed to human exposure to $PM_{2.5}$.

The data used for the calculations was collected between 2009 and 2013 per 100 000 inhabitants; 2009 was the 1st year when $PM_{2.5}$ data was collected in Kraków. Total mortality attributed to exposure to $PM_{2.5}$ was approximately equal to 45 deaths per year per 100 000 inhabitants, which was higher than that attributed to exposure to PM_{10}.

Significantly lower values of total mortality were obtained when examining the influence of NO_2 concentrations. The relevant data can be seen in Figure 7.

Total mortality due to NO_2 exposure was approximately equal to 10 deaths per year per 100 000 inhabitants. Concentrations of NO_2 decreased during the period of studies. However, concentrations of both PM_{10} and $PM_{2.5}$ remain high. For this reason, air pollutants continue to have a significant influence on human health. The highest impact on total mortality was due to exposure to $PM_{2.5}$ and the 2nd highest was due to PM_{10}. During the period 2005–2013 the lowest impact on total mortality was due to NO_2. Total mortality attributed to exposure to PM_{10} and $PM_{2.5}$ was 4–5 times higher than the total mortality attributed to exposure to NO_2.

Figure 8 shows the calculated health impact of PM_{10} exposure in the years 2006 and 2013.

Those are years with the lowest and highest estimated numbers. The highest annual concentration of PM_{10} was observed in 2006, and the lowest annual concentration

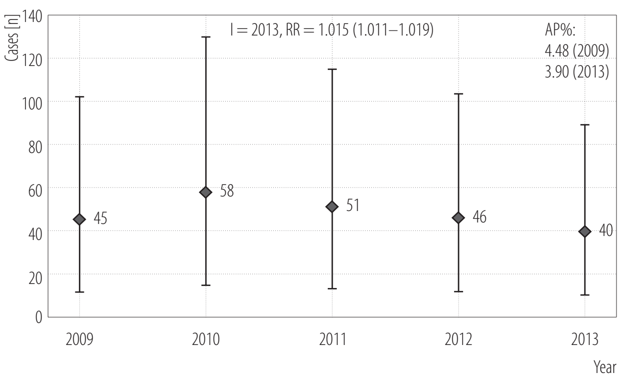

Fig. 6. Calculated total mortality attributed to exposure to $PM_{2.5}$, Kraków, Poland, 2009–2013

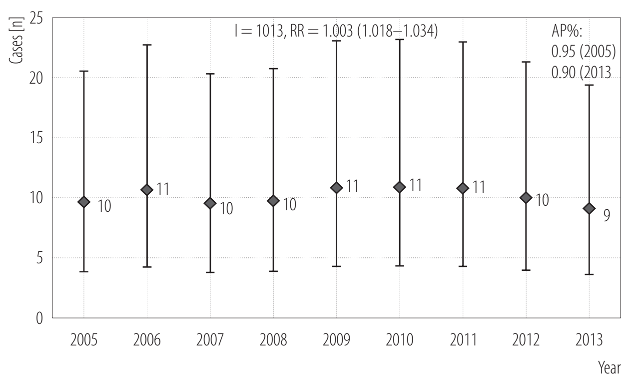

Fig. 7. Calculated total mortality attributed to exposure to NO_2, Kraków, Poland, 2005–2013

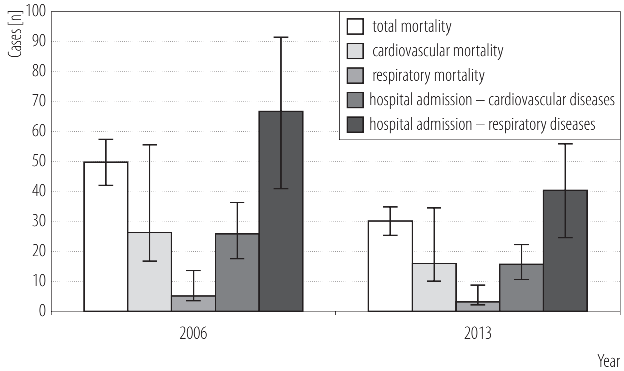

Fig. 8. Comparative results of the calculated health impact attributed to exposure to PM_{10}, Kraków, Poland, 2006 and 2013

of PM_{10} was reported in 2013. Accordingly, the highest (2006) and the lowest (2013) numbers of cases attributed to exposure to air pollution were observed. The estimated total mortality determined for 2006 equalled 50 per 100 000 inhabitants and dropped to 30 per 100 000 inhabitants in 2013. The number of estimated cases for the year 2013 was almost 2 times lower than that for 2006. The estimated cardiovascular mortality reached 50% of the total mortality for the years 2006 and 2013. In contrast, the estimated respiratory mortality constituted only 10% of the estimated total mortality in both years. The estimated cardiovascular mortality was comparable to the estimated hospital admissions due to cardiovascular diseases. However, the estimated hospital admissions caused by respiratory diseases were 13 times higher than the estimated respiratory mortality.

The results obtained for this study for Kraków, Poland were compared with the results calculated by Sega and Beslic for Zagreb, Croatia [17,18]. The calculated mean values of all the examined health effects were almost 2 times lower for Zagreb than they were for Kraków. This can be related to the varying levels of PM_{10} in the 2 cities. Strukova et al. have performed similar studies and obtained similar values in 2006 for Ukraine and Russia [19]. Baccini et al. have performed studies focused on the health impact of PM_{10} in a number of Italian cities during the years 2003–2006. The authors have obtained lower values of the total mortality attributed to PM_{10} than the values observed in this study. Only a single city, i.e., Milan, in Italy showed higher values of total mortality than Kraków [20]. Research performed for Sao Paulo, Brazil during the years 1998–2008 showed cardiovascular mortality equal to 55.9 per 100 000 inhabitants and respiratory mortality equal to 15.6 per 100 000 inhabitants [21]. The numbers are much higher than those obtained in this study.

The value of total mortality in 2013 for inhabitants exposed to $PM_{2.5}$ in Poland was lower than that for Europe [9] and the world in general [9]. The lowest value was obtained for Australia and the highest for East Asia. It is also worth mentioning that some literature values were reported for an age group above 30 and between the years 1850–2000 [9].

Studies performed in Spain [22] have shown results of the health impact of $PM_{2.5}$. The authors have obtained values of total mortality attributed to exposure to $PM_{2.5}$, which ranged between 10–30 per 100 000 inhabitants in the year 2007. In this work, a corresponding value of 45 was found for the year 2009. The World Health Organization epidemiological studies show total mortality due to exposure of NO_2 equal to 21 per 100 000 inhabitants for Europe [23]. It is almost 2 times higher than the value obtained in this work for Kraków.

It is worth mentioning that during the years 2009–2013 $PM_{2.5}$ concentration dropped by 15.9%, which was accompanied by a drop in total mortality attributed to $PM_{2.5}$ of 12.8% in the city of Kraków. Similar calculations have shown that in Kraków, in the 2005–2013 time period, concentration of PM_{10} was lowered by 23% and attributable health effects dropped by about 26%. In the case of NO_2, in the same period of time, a decrease in concentration of 4.8% was observed. Additionally, total mortality attributed to exposure to NO_2 decreased by 6%.

Lack of individual characteristics constitutes a limitation of the performed studies. It is assumed that exposure measured in the central monitoring sites is representative of a larger area and hence, its effect on a broad population range can be stated. Also, a limitation of this study is the fact that in the year 2010 residential site location was moved from Krowodrza to Kurdwanów.

CONCLUSIONS

Total mortality attributed to PM_{10} dropped by 26% from the year 2005 to 2013. During the same period of time cardiovascular mortality dropped by 26%. Cardiovascular mortality constituted 50% of the total mortality. During the time considered in this work cardiovascular mortality was 5 times higher than respiratory mortality.

The results obtained by the use of the AirQ software for Kraków imply that exposure to polluted air can result in serious health problems. It would be beneficial to perform an analysis of epidemiological data for the city in comparison with the results presented in this manuscript to obtain a more detailed insight into the impact of air pollution on human health.

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