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THE IMPACT OF ROAD TRANSPORT ON AIR QUALITY IN SELECTED POLISH CITIES

WPŁYW TRANSPORTU NA JAKOŚĆ POWIETRZA W WYBRANYCH MIASTACH POLSKI

Abstract: Road transport is widely recognised to be a significant and increasing source of air pollution. In the next few decades, road transport will remain a significant contributor to air pollution in European cities. According to National Centre for Emissions Management (KOBiZE) carbon dioxide and carbon monoxide (CO_2 and CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC) and particulate matter have the highest share of emissions from transport in Poland. The aim of the paper was to study trends of concentrations changes of CO, NO_2, NO_x, O_3, PM10 and PM2.5 in 2010–2015 in selected Polish cities (Poznan, Wroclaw, Krakow, and Warszawa). The analysis of the data showed that European cities have the problem of air pollution by particulate matter (PM). For the CO, NO_2, NO_x, O_3 acceptable concentrations established for human health are not exceeded. Concentrations of pollutants were higher on the traffic stations. At the same time, the highest concentration of pollutants was found in Krakow. In conclusion, air quality in cities under study was influenced by both transport and geographical location.

Keywords: road transport, air quality, polish cities, particulate matter, gas pollutions

Introduction

Transport plays a very important role in the functioning of society, facilitates access to culture, work, services and determines the development of cities. Car transport has a special place as it is widely available. The increase in the number of used cars,

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however, contributes to the increase of pollutant emissions into the air, especially in urban agglomerations. Most urban car journeys are less than 6 km long, while the efficiency of the catalytic converters in the first few minutes of their operations is low, so the volume of exhaust emissions in urban areas is so significant [1]. In addition, in most cars the exhaust systems do not work at all or they are defective. According to Emission Analytics data, 97 % of diesel cars do not meet emissions standards, and some models exceed the norms 13 times. These figures are all the more alarming as they concern new cars [2]. In Western Europe, emissions from road transport are the most important source of pollutant emissions into the air, while in Eastern Europe, it is just behind emissions from the communal and household sector. The remaining major sources of emissions are industry, power industry and agriculture. Transport emissions are largely responsible for the formation of acid rain, the formation of tropospheric ozone, and climate changes. Their impact on human health is also significant [3–6]. A separate issue related to road transport is the nuisances caused by the noise and vibration resulting from the movement of vehicles.

Pollution emitted to the atmosphere from the transport sector comes mainly from the combustion of fuels in automobile engines. An important source is also the emission from the abrasion of structural components of vehicles and road pavement and the resuspension of dust [6]. The main pollutants emitted from the transport are carbon dioxide CO_2, carbon monoxide CO, sulphur dioxide SO_2, nitrogen oxides NO_x, particulate matter PM10, particulate matter PM2.5 and non-methane volatile organic compounds NMVOC [3–6].

In Europe, the transport sector is primarily responsible for emissions of NO_x. In 2014 emissions from transport accounted for 46 % of total NO_x emissions in 28 EU countries [3]. With the introduction of stringent emission standards (Euro 6), the reduction of NO_x emissions from transport has been forecasted, but unfortunately, the drop is not so significant. Real-time emissions are often higher than those in the laboratory where homologation tests are performed. This problem occurs especially in vehicles with diesel engines [3, 4, 8]. Road transport also contributes to the increase of suspended particulate concentrations, according to European Environmental Agency (EEA) data, in road transport in 2014, it accounted for 13 % of total primary PM10 dust emissions and 15 % of PM2.5 emissions. Increased dust concentration is also contributed by the emissions from road pavement and non-exhaust emissions. It is estimated that non-exhaust emission represents 50 % of primary PM10 emissions and approx. 22 % of primary PM2.5 emissions [9]. Of important is also the secondary sling load of dust from the roads. In the EU countries in the years 2000–2014 there was a drop in emissions of SO_x (by 80 %), NO_x (by 40 %), NH_3 (by 50 %), PM10 (by 35 %), PM2.5 (by 40 %), NMVOC (50 %), CO (by 70 %), BC (by 50 %) and CH_4 (by 50 %) in the transport sector. However, the release of the dangerous BaP has increased by 50 %. The analysis of emission data shows that the highest emission reductions were found for SO_x and CO, while the lowest was for PM10 [3]. Heavy metal emission (As, Cd, Ni and Hg) from the transport in the years 2000–2014 remained at a similar level. Only Pb emissions decreased significantly (by about 70 %).

Access to resources such as coal has made individual heating of buildings the most important source of emissions in Poland, especially in the autumn and winter seasons. Road transport, however, is also an important source of emissions. According to [10] data, in 2014, mobile sources were responsible for 22 % of total dust emissions of total suspended particles (TSP) and for 44 % of NO_x emissions (Fig. 1). According to the National Centre for Emissions Management (KOBiZE), the largest share of emissions from road transport in Poland is: CO_2 and CO (in 2014 respectively: 4233.3 and 563.1 thousand Mg), NO_x (220.6 thousand Mg), NMVOC (117.2 thousand Mg) and dust (including dust in general term TSP: 74.7 thousand Mg).

Fig. 1. Emission sources of TSP and NO_x in Poland in 2014 (source: own elaboration based on [10])

According to the Ministry of Digital Affairs, the number of vehicles in Poland is growing year by year. In the years 2000–2015, the number of passenger cars almost doubled to 20 723 thousand units. A similar situation can be observed for lorries (3482 thousand units) as well as motorcycles and scooters (1272 thousand units). Only about 9 % of the Polish fleet are relatively new vehicles (Table 1) [11].

Table 1

Automobiles and tractors by age group in 2015

Specification	Passenger cars		Buses		Lorries		Tractor units	
	unit	[%]	unit	[%]	unit	[%]	unit	[%]
Total	20723423	100.0	1098440	100.0	3098376	100.0	329589	100.0
up to 2 years old	885473	4.3	4846	4.4	166272	5.4	45496	13.8
3 to 5	1047676	5.1	4524	4.1	229028	7.4	43425	13.2
6 to 9	2261651	10.9	9403	8.6	379340	12.2	75664	23.0
10 to 15	5042087	24.3	20124	18.3	695302	22.4	70694	21.4
16 to 20	4710323	22.7	20187	18.4	552955	17.9	41486	12.6
21 to 30	4064565	19.6	29307	26.7	526761	17.0	36377	11.0
31 years and older	2711648	13.1	21453	19.5	548718	17.7	16447	5.0

Source: own elaboration based on [11].

While more than 70 % of passenger cars driving on Polish roads are vehicles older than 10 years characterised by poor efficiency of the exhaust after-treatment system or a total lack thereof. Taking into account the increasing number of vehicles, the increased traffic volume during peak hours and the current road structure, this may be an important factor contributing to the deterioration of air quality in Polish cities.

The aim of the study was to assess the impact of transport on air quality in selected four Polish cities: Warszawa, Krakow, Wroclaw and Poznan, along with an analysis of existing and planned transport solutions and its impact on the reduction of air pollution level combined with the aspects of mobility management in the urban agglomeration.

Materials and methods

The data used in the study come from the Chief Inspectorate of Environmental Protection database, whose resources are available on the CIEP Air Quality Portal. Four urban agglomerations were selected for the analysis: Warszawa, Krakow, Wroclaw and Poznan. These are large academic, cultural and industrial centers with high traffic levels. In each of the above-mentioned locations, two air monitoring stations were selected: one was a city background station, the other was a traffic station designed to measure the level of pollution from road transport (Table 2).

Table 2

The stations from which the data used in the study originated

Station code	Station type	City
DsWrocAlWisn	traffic	Wroclaw
DsWrocNaGrob	background	Wroclaw
DsWrocWybCon	background	Wroclaw
MpKrakAlKras	traffic	Krakow
MpKrakBujaka	background	Krakow
MpKrakBulwar	industrial	Krakow
MzWarAlNiepo	traffic	Warszawa
MzWarKondrat	background	Warszawa
MzWarWokalna	background	Warszawa
WpPoznDabrow	background	Poznan
WpPoznPolank	background	Poznan

The exception was Poznan, where both measuring points are city background stations – there is no traffic station in the city. In the case of Krakow, the results of measurements of CO concentrations come from the traffic and industrial stations (MpKrakBulwar). For concentrations of CO, NO_x, NO_2, O_3, PM10 and PM2.5 basic statistics have been calculated: S_a (annual average), $S_{8\ max}$ (maximum 8-hour average), $L > 200$ (number of results for 1 hour above 200 μg/m^3), *Perc. 99.8* (percentile 99.8 from 1-hour values), $L > 120$ (number of daily maxima with avg. in 8 hours above 120 μg/m^3), *Per. S93.2* (percentile 93.2 from the series of daily maxima with avg. in 8 hours), $L > 50$ (number of results for 24 hours above 50 μg/m^3) and *Perc. 90.4* (percentile 90.4 from 24-hour results) (Table 3). The report also presents the annual course of daily mean rates for NO_2, NO_x, PM10 and PM2.5 in 2015 (Fig. 2). The graphs show the mean daily concentrations of PM10 and NO_2 in 2015. The measuring stations used in the study are handled by the Chief Inspectorate of Environmental Protection, they belong to the air monitoring network and the measurements of pollutants are performed automatically and manually using reference methods or compatible with them [12].

Measurement results and their discussion

The results of analyses and calculations are presented in Table 3 and Figures 2 and 3. In the case of CO, S_a and *S8max* were measured from the hourly data collected from the measurement stations. Statistics are for years 2010–2015. Based on them, it was observed that higher concentrations of CO were always present at traffic stations, although these were not very significant differences. Concentration levels in individual years were at a similar level, no clear fluctuations were observed. The highest S_a as well as $S_{8\ max}$ were in Krakow, while the lowest in Poznan and Warszawa. It should be noted that the differences in values were not large.

NO_x are considered to be pollutants emitted mainly from the road transport sector and the analyses have confirmed the connection between NO_x emissions and transport sector. Traffic stations found significantly higher S_a NO_x concentrations compared to background stations. In the Polish law, the NO_x standard is only determined by the plant protection assessment, so the results of measurements from urban agglomerations are not included in annual air quality assessments. Nevertheless, referring to the standard that is 30 $\mu g/m^3$ it can be stated that the concentration of NO_x in cities is very high, especially directly near the communication arteries.

In the case of NO_2 calculations concerned S_a, $L > 200$ (with S1) and *Perc. 99.8*. The standard for S_a NO_2 is 40 $\mu g/m^3$. From the conducted analyses we can observe that in the years 2010–2015 it was exceeded every year on all analysed traffic stations. In the case of background stations, the exceedances were not recorded. In addition, concentrations at traffic stations were 100 % higher than on background stations. This is yet another proof of the influence of mobile sources on air quality in urban areas. $L >$ 200 exceedances were observed only at traffic stations, which may indicate the impact of mobile emissions on episodes with very high levels of pollution that are a serious health hazard for residents. As in the case of S_a and $L > 200$, the value of *Perc. 99.8* were also higher at traffic stations.

Ground level O_3 formation is influenced by many factors. Suitable climatic conditions, such as relative humidity, high temperature (>18 ^oC), and most importantly – the high intensity of solar radiation are necessary. Another factor influencing the formation of ozone is wind speed [13, 14]. As O_3 is a secondary pollution, resulting from photochemical changes, precursors are necessary for its formation. The most important are NO_x, CO, NMVOC produced mainly by the combustion of liquid fuels in automotive engines [2, 13, 14]. The formation of O_3 is strongly dependent on the availability of NO_x. When their concentration is low, O_3 is consumed by photochemical oxidation, and if their concentration is increased, the tropospheric O_3 synthesis occurs

Table 3

Statistics calculated for individual pollutants for years 2010–2015

Year	City	Station type	Station code	S_a CO [mg/m^3]	$S_{8\,max}$ CO [mg/m^3]	S_a NOx [μg/m^3]	S_a NO_2 [μg/m^3]	$L > 200$ NO_2 [-]	*Perc. 99.8* NO_2 [μg/m^3]	S_a O_3 [μg/m^3]	$L > 120$ O_3 [-]	*Per. S93.2* O_3 [μg/m^3]	S_a PM10 [μg/m^3]	*L > 50* PM10	*Perc. 90.4* PM10 [μg/m^3]	S_a PM2.5 [μg/m^3]
2010	Wroclaw	traffic	DsWrocAlWisn	0.7	2.8	**190.4**	**69.7**	2	161.0	na	na	na	**61.9**	**183**	111.0	**na**
2011	Wroclaw	traffic	DsWrocAlWisn	0.6	4.2	**182.7**	**64.3**	5	181.0	na	na	na	**53.1**	**146**	97.0	**32.3**
2012	Wroclaw	traffic	DsWrocAlWisn	na	na	**158.5**	**55.8**	0	149.0	na	na	na	na	na	na	**30.7**
2013	Wroclaw	traffic	DsWrocAlWisn	na	na	**150.1**	**54.4**	0	139.0	na	na	na	na	na	na	**30.4**
2014	Wroclaw	traffic	DsWrocAlWisn	0.6	4.3	**157.1**	**53.3**	1	146.0	na	na	na	na	na	na	**28.6**
2015	Wroclaw	traffic	DsWrocAlWisn	0.6	4.5	**150.0**	**53.8**	3	161.9	na	na	na	na	na	na	**30.3**
2010	Wroclaw	background	DsWrocWybCon	0.4	2.9	**42.4**	29.2	0	104.0	43.6	9	105.8	na	na	na	**31.9**
2011	Wroclaw	background	DsWrocWybCon	0.4	2.4	**47.3**	32.0	0	129.0	45.8	14	116.0	38.8	**54**	80.0	**28.3**
2012	Wroclaw	background	DsWrocWybCon	0.4	2.6	**37.2**	24.3	0	91.0	48.2	13	113.8	38.1	**71**	86.0	**26.8**
2013	Wroclaw	background	DsWrocWybCon	na	na	26.9	20.3	0	78.0	42.9	3	96.8	36.5	**77**	63.2	**27.8**
2014	Wroclaw	background	DsWrocWybCon	0.4	4.4	**43.9**	25.7	0	107.0	37.8	5	102.3	37.7	**73**	66.4	23.1
2015	Wroclaw	background	DsWrocWybCon	0.4	3.0	**40.0**	24.7	0	95.7	47.6	24	119.1	36.6	**69**	66.0	22.9
2010	Krakow	traffic	MpKrakAlKras	1.3	5.8	**243.6**	**70.4**	0	171.0	na	na	na	**79.0**	**223**	150.8	**61.1**
2011	Krakow	traffic	MpKrakAlKras	1.1	6.3	**251.0**	**73.1**	5	179.0	na	na	na	**76.6**	**200**	151.8	**55.0**
2012	Krakow	traffic	MpKrakAlKras	1.0	4.5	**231.5**	**71.5**	3	187.0	na	na	na	**65.9**	**132**	134.7	**46.2**
2013	Krakow	traffic	MpKrakAlKras	1.1	4.2	**234.6**	**68.0**	0	173.0	na	na	na	**59.7**	**158**	112.7	**43.5**
2014	Krakow	traffic	MpKrakAlKras	1.1	4.8	**229.0**	**61.5**	0	155.0	na	na	na	**63.9**	**188**	128.1	**45.0**
2015	Krakow	traffic	MpKrakAlKras	0.9	3.4	**215.4**	**63.1**	1	157.9	na	na	na	**67.8**	**200**	132.4	**43.8**
2010	Krakow	background	MpKrakBujaka*	0.7	4.0	**87.6**	33.6	0	125.0	33.7	6	100.9	**47.9**	**65**	103.0	**35.6**
2011	Krakow	background	MpKrakBujaka*	0.6	3.6	**88.0**	31.7	0	133.0	31.4	1	91.3	**54.2**	**127**	121.0	**37.3**
2012	Krakow	background	MpKrakBujaka*	0.6	4.0	**83.6**	32.2	0	123.0	34.3	9	106.5	**53.5**	**116**	110.0	**41.3**
2013	Krakow	background	MpKrakBujaka*	0.6	3.2	**72.6**	27.5	0	111.0	34.3	4	96.5	**44.4**	**106**	94.0	**33.4**
2014	Krakow	background	MpKrakBujaka*	0.7	3.6	**80.2**	28.5	0	124.0	32.7	2	100.0	**46.3**	**100**	96.0	**33.0**
2015	Krakow	background	MpKrakBujaka*	0.6	3.0	**83.0**	31.9	0	128.4	38.2	23	119.2	**45.1**	**99**	90.0	**33.7**
2010	Warszawa	traffic	MzWarAlNiepo	0.8	2.9	**154.5**	**60.4**	1	177.8	na	na	na	**52.4**	**150**	89.2	na

Table 3 contd.

Year	City	Station type	Station code	S_a CO [mg/m^3]	$S_{8\,max}$ CO [mg/m^3]	S_a NOx [μg/m^3]	S_a NO_2 [μg/m^3]	$L > 200$ NO_2 [-]	*Perc. 99.8* NO_2 [μg/m^3]	S_a O_3 [μg/m^3]	$L > 120$ O_3 [-]	*Per. S93.2* O_3 [μg/m^3]	S_a PM10 [μg/m^3]	$L > 50$ PM10	*Perc. 90.4* PM10 [μg/m^3]	S_a PM2.5 [μg/m^3]
2011	Warszawa	traffic	MzWarAlNiepo	0.7	3.1	**143.2**	**54.8**	5	170.4	na	na	na	**49.1**	**129**	80.2	**31.6**
2012	Warszawa	traffic	MzWarAlNiepo	0.7	3.3	**144.8**	**45.4**	1	143.5	na	na	na	38.6	**50**	59.4	**25.1**
2013	Warszawa	traffic	MzWarAlNiepo	0.7	2.3	**139.2**	**56.3**	8	180.3	na	na	na	39.7	**75**	63.6	**31.2**
2014	Warszawa	traffic	MzWarAlNiepo	0.7	2.5	**125.4**	**49.0**	1	166.3	na	na	na	**41.7**	**84**	65.5	**29.9**
2015	Warszawa	traffic	MzWarAlNiepo	0.6	2.2	**160.5**	**59.2**	6	184.1	na	na	na	**41.1**	**80**	71.4	24.1
2010	Warszawa	background	MzWarWokalna**	0.3	2.1	29.2	21.4	0	91.2	47.1	15	110.4	35.0	**48**	63.2	**28.3**
2011	Warszawa	background	MzWarWokalna**	0.4	3.0	**31.1**	20.7	0	110.5	45.6	6	108.1	35.9	**56**	65.1	24.2
2012	Warszawa	background	MzWarWokalna**	0.4	4.8	**32.1**	24.0	0	110.2	44.8	9	110.2	37.2	**72**	64.9	**28.7**
2013	Warszawa	background	MzWarWokalna**	0.4	2.8	**32.9**	24.0	0	95.2	46.0	13	112.6	33.8	**46**	55.2	22.4
2014	Warszawa	background	MzWarWokalna**	0.4	2.9	**31.6**	22.2	0	105.5	44.6	6	110.2	29.3	**36**	51.2	23.0
2015	Warszawa	background	MzWarWokalna**	0.4	3.0	**33.1**	24.1	0	119.9	45.7	18	113.6	31.5	**41**	53.7	21.0
2010	Poznan	background	WpPoznDabrow	0.4	2.9	**42.9**	26.8	0	117.9	43.4	8	106.0	37.7	**81**	81.5	**30.9**
2011	Poznan	background	WpPoznDabrow	0.3	3.5	**48.2**	27.7	7	159.2	44.6	11	112.3	39.1	**90**	80.5	**27.5**
2012	Poznan	background	WpPoznDabrow	0.3	2.1	**44.8**	26.2	1	131.3	42.2	10	107.6	33.2	**59**	62.9	24.4
2013	Poznan	background	WpPoznDabrow	0.3	2.9	**30.6**	19.7	0	111.3	44.6	6	105.1	24.8	28	44.6	23.4
2014	Poznan	background	WpPoznDabrow	0.3	2.7	**34.4**	19.5	0	91.7	39.9	11	111.3	33.0	**51**	59.2	**26.4**
2015	Poznan	background	WpPoznDabrow	0.3	2.3	**44.0**	24.7	0	132.9	45.5	**26**	123.8	31.3	**55**	60.4	24.4
2010	Poznan	background	WpPoznPolank	0.4	3.2	**33.3**	21.3	0	89.5	na	na	na	38.4	**80**	82.8	na
2011	Poznan	background	WpPoznPolank	0.4	2.7	**35.9**	21.6	0	101.4	na	na	na	39.0	**84**	80.6	na
2012	Poznan	background	WpPoznPolank	0.3	4.5	**31.4**	19.5	0	87.0	na	na	na	36.2	**69**	75.7	na
2013	Poznan	background	WpPoznPolank	0.3	2.1	26.5	19.2	0	80.6	na	na	na	29.5	**44**	55.0	na
2014	Poznan	background	WpPoznPolank	0.4	2.6	**32.9**	21.5	0	95.5	na	na	na	35.7	**69**	63.3	na
2015	Poznan	background	WpPoznPolank	0.4	2.3	**36.8**	24.2	0	108.8	na	na	na	34.7	**54**	65.6	na

* CO measurements in Krakow were carried out on an industrial type station with code MpKrakBulwar.

** PCO measurements in Warszawa were carried out on a background type station with code MzWarKondrat.

The table outlines the values that exceed the applicable limits, as defined by law. The designation "na" indicates the lack of data for an individual station and pollution or its availability, but not inclusion in the analyses.

[13]. As O_3 is not emitted directly from mobile sources, its concentration at traffic stations is not tested. Precursors of the formation can be transported over long distances, so often higher concentrations of O_3 can be found in out-of-town and suburban stations rather than in stations located in urban agglomerations. In the Polish law, 25 days are allowed with an 8-hour average above 120 μg/m^3, averaged over the next three years, in the years 2010–2015 at selected stations this value was exceeded only once at the station in Poznan at Dabrowskiego street, reaching the number of 26 days. Average annual concentrations remained at a similar low level within the limits 31.4–48.2 μg/m^3.

For PM10 suspended particulates calculations were done concerning S_a, $L > 50$ and *Perc. 90.4*. Data analysis shows that the average annual concentration, for which the standard is 40 μg/m^3, in the years 2010–2015 was exceeded twice in Wroclaw at the traffic station, 12 times in Krakow (6 times at the traffic station and 6 at the background station) and 4 times in Warszawa at the traffic station. Higher concentrations were observed at traffic stations (38.6–79.0 μg/m^3). According to the law in force, 35 days with the values above 50 μg/m^3 are allowed in a year. In the analysed period, this value was met only once in Poznan at Dabrowskiego street. Higher values of $L > 50$ were

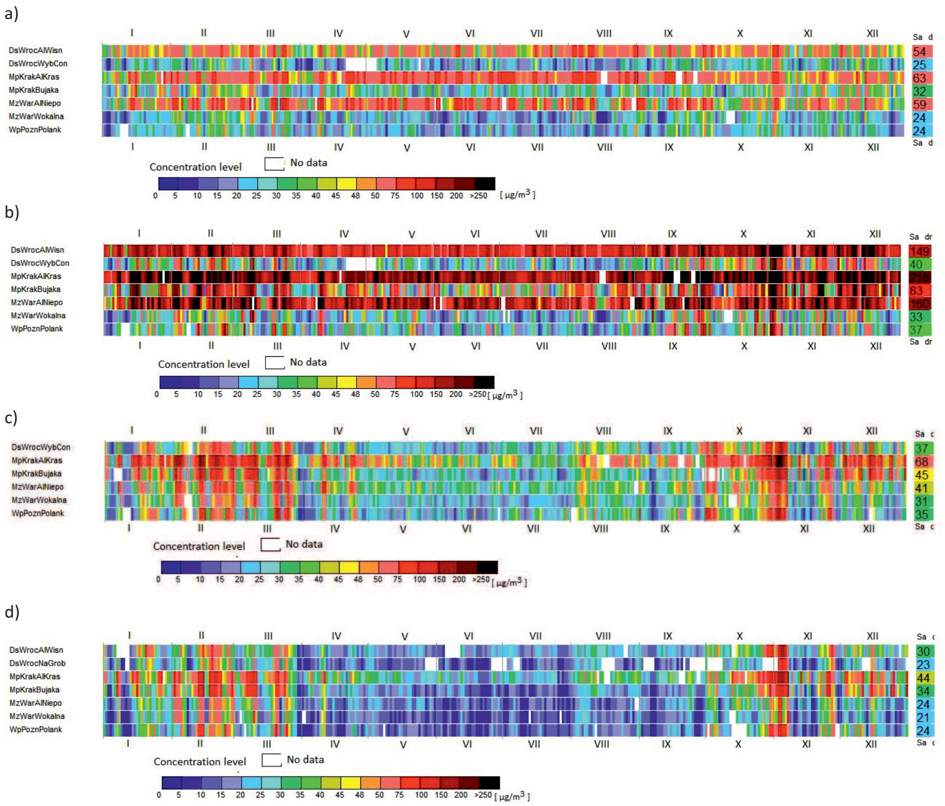

Fig. 2. Annual course of average daily concentrations of a) NO_2, b) NO_x, c) PM10 and d) PM2.5 in 2015 (source: own elaboration on the basis of [15])

found again at traffic stations. A similar relationship was observed for *Perc. 90.4* – higher values occurred at traffic stations.

Higher mean annual concentrations of PM2.5 (S_a), as in previous cases, were found at the traffic stations. The highest concentrations occurred in Krakow and the lowest background stations in Poznan and Warszawa. The mean annual standard for PM2.5 has been 25 μg/m^3 since 2015. There was a margin of tolerance before. However, with reference to the current values, it can be noted that this value was repeatedly exceeded in the period under review. The standard was only observed in 10 cases: 2 times in Wroclaw at the traffic station, 5 times in Warszawa (1 time at the traffic station, 4 times at the background station) and 3 times in Poznan at the background station.

Mosaic charts show the annual average daily concentrations of NO_2, NO_x, PM10 and PM2.5 in 2015 (Fig. 2). They clearly show that higher concentrations of pollutants occurred at traffic stations. In addition, in the case of traffic stations, high concentrations were maintained at a similar level throughout the year; in the case of background stations, higher concentrations were observed in the autumn-winter season. This demonstrates the significant, and what is important, the equal impact of emissions from mobile sources throughout the year on air quality in urban agglomerations. From the analysis of the charts, it can be concluded that NO_x emissions are strongly associated with mobile sources. In the case of the background station, NO_x emissions in their surroundings were significantly lower. In addition, there was no significant increase in concentrations in the cooler months. High concentrations of dust pollution only in the cool season at the background stations indicates the impact of low emissions from the communal and household sector on urban air quality.

Daily variability of pollutant concentrations may indicate the impact of a given emission source on air quality. Figure 3 shows the annual mean average daily course for PM10 and NO_2. In the case of PM10, a similar level of concentration was observed throughout the day, slightly increasing in the afternoon and remaining at that level until early morning hours. There is also a morning increase in concentrations associated with the traffic peak. In the case of NO_2 there was a noticeable increase in morning and afternoon concentrations, and this trend was significantly more pronounced in the traffic stations. This phenomenon is related to the daily rhythm of the functioning of society. Residents of urban agglomerations travel in the morning to work and school, at this time there is an increase in car traffic and therefore an increase in NO_2 concentrations, which is a product of fuel combustion in car engines, again increase in car traffic and at the same time NO_2 concentrations are observed in the afternoon when they start returning home. After the residents have returned to their homes, they start to warm up their homes, which relates to an increase in PM10 concentrations during these hours, especially in cities where the share of particulate matter emissions in the communal and household sector is significant.

The share of car transport in generating air pollutant concentration varies in the analysed cities. It can also be different in different parts of the city. It is related to the road layout, the density of streets and their traffic load and fluidity, the limitation of ventilation by the building and the presence of other sources of emission. In the case of Warszawa as the capital of Poland, transport can be regarded as the predominant factor

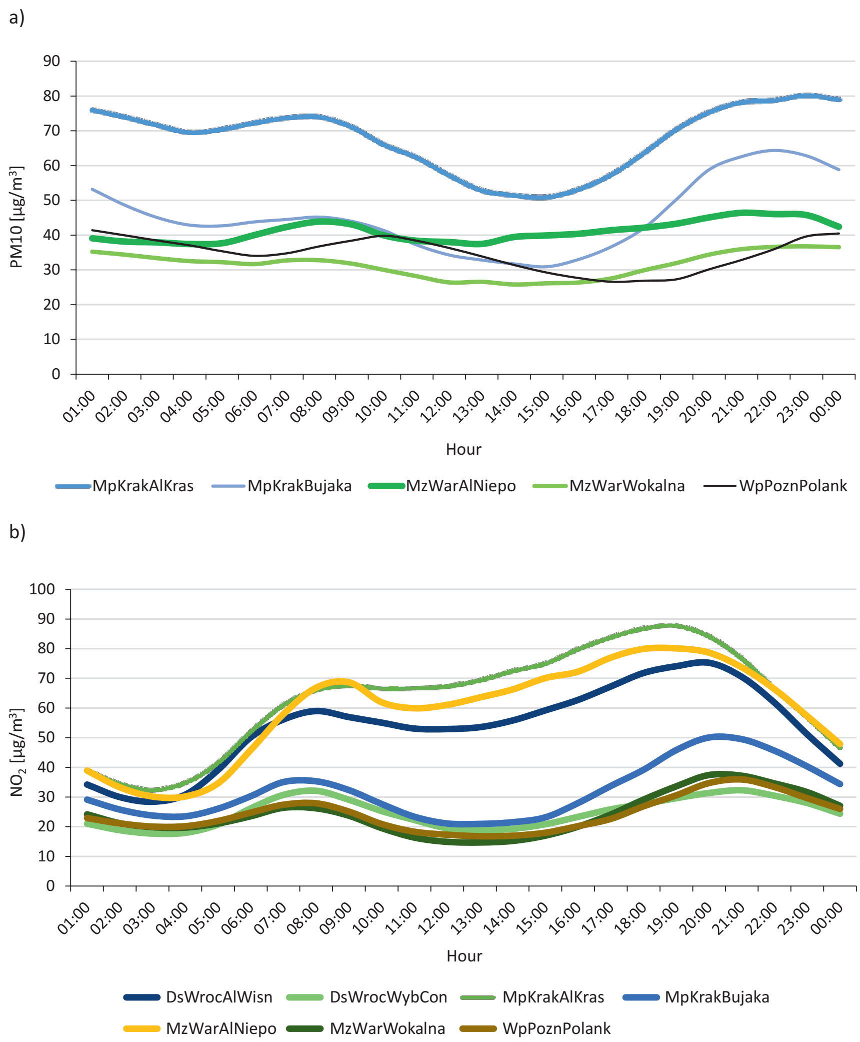

Fig. 3. Average daily course of concentrations of a) PM10 and b) NO_2 in 2015 (source: own elaboration on the basis of [15])

of air pollution, especially in relation to the central area of the city and the main roads. This is confirmed by model calculations performed, e.g. for the purposes of developing an air protection program [16] for the Warszawa agglomeration zone and for air quality assessments [17]. The structure of PM10 dust emissions in Warszawa for 2011, presented in the first of these documents, indicates a 63 % share of car communication in the total emissions of this pollution originating in the city area. In the case of NO_2, this ratio is 51 %, but the indicated high share of point emitters (industrial, 46 %) does not have a direct effect on the concentration of this substance in the city. This is illustrated by, for example, calculations of airborne concentrations of NO_2, originating from different emission categories. Average annual concentrations of nitrogen dioxide from transport reached 41.3 μg/m^3, while the maximum concentration from the total emission amounted to 47.5 μg/m^3. Pollution from high point emitters is largely transported outside the city and does not directly affect the levels of concentration in its area.

The share of transport in the average annual concentrations of PM10 dust in Warszawa, estimated on the basis of mathematical modelling for 2015, is over 80 % (Fig. 4). It diminishes as it approaches the periphery areas of the city for local surface emissions (individual heating systems) and the influx of pollutants from the suburbs, where there is a large impact of the communal and household sector.

The presented situation for Warszawa regarding PM10 air pollution involves, among

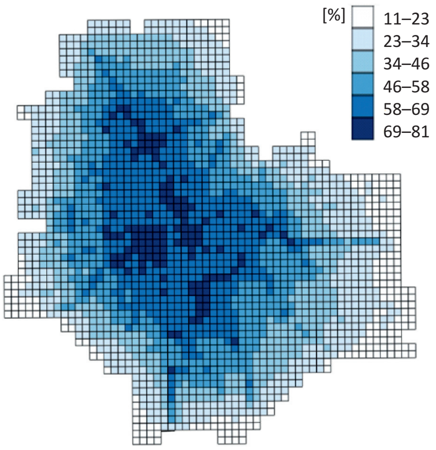

Fig. 4. Percentage share of transport emissions in the average annual PM10 concentration in Warszawa in 2015 (source: own elaboration based on [18])

other things, a well-developed gas and heat network in the city, so the pressure from the so-called „low emission" is relatively small in a large area. These shares are formed differently in cities where the effects of individual solid fuel heating appliances are high in different regions. An example may be Krakow, where „low emission" is the decisive factor for pollution, but the share of transport is also significant.

Characteristics of selected existing and planned solutions limiting the impact of transport on urban air pollution

Improvement of air quality is the subject of actions of cities in Poland, and some of them concern the reduction of negative impact of transport. Various types of planned solutions are mentioned in strategic and planning documents concerning transport policy, spatial planning, transport development plans, investment plans and environmental programs. Krakow was the first city, whose authorities in 1993 adopted a transport policy that included the principles of sustainable transport development. In 1995 a similar policy was formulated by the Warszawa authorities [19]. In 1999, the Poznan City Council adopted the Transport Policy of the City of Poznan, which aims to „achieve a sustainable transport system in terms of economic, spatial, ecological and social aspects". These documents are obviously being updated. For example, in 2009, the Strategy for Sustainable Development of Warszawa Transport System by 2015 and for subsequent years was adopted. On 8 June 2016, the City Council of Krakow adopted a new Transport policy for the city of Krakow for the years 2016–2025. Among its five main objectives, the two directly address environmental impacts of transport, that is the development and promotion of ecological forms of travel and improvement of the environment, reduction of a nuisance of transport for residents and increase of safety.

Directional measures and concrete solutions are also included in the air protection programs developed for individual cities. They focus, among other things, on reducing or eliminating individual local transit traffic in cities or their separated areas, developing integrated traffic management systems, developing and promoting public transport systems, shaping appropriate pricing policies for public transport and parking, construction Park & Ride type car parks, the introduction of low-carbon fuels and technology, street cleaning, the development of bicycle routes and the modernisation of existing streets.

An important tool to help minimise the negative impact of individual transport on air quality is the plan for sustainable development of public transport, which is a mandatory instrument drawn up by a local government unit that sets the desired standard for public transport services, including the need to ensure environmental protection [20]. The public transport law in force in Poland also projects a metropolitan union as a public transport organiser and at the same time the unit drawing up a transport plan [20]. This is justified by the fact that modern transport challenges of cities such as Warszawa, Krakow, Wroclaw and Poznan are generated by the economic recovery and demographic development in suburban areas. The dynamic and exuberant process of suburbanization taking place without the legal possibility of regulating the regional level of planning causes the formation of settlement structures unrelated to the main public transport corridors. As a result of uncoordinated urban sprawl while increasing mobility and price availability of individual vehicles, traffic growth and depletion of transport infrastructure performance are degrading. As a result, this congestion increases the air pollution. The number of passenger cars used in Poland has increased by 86 % compared to the 2002 figures and amounted to 539 cars per 1000 inhabitants in 2015 [21]. Spatial mobility in cities and suburban areas is one of the arguments for changing the perception of a city, not limited to administrative boundaries, but taking into account the area of influence, the so-called functional area or metropolitan area. The possibility of creating plans for the sustainable development of collective transport in metropolitan areas provided by the Act on Collective Public Transport, remains at the current legal and legislative stage only a potential possibility, as legislative changes carried out in the Polish Parliament halted the bottom-up possibilities, resulting from the actions of local governments, of creating metropolitan unions.

The plans for the sustainable development of public transport are thus atomised in accordance with the competence of local governments for areas covered only by the administrative boundaries of cities and municipalities with extended territorial coverage only in the context of the existing public transport organisation agreement for neighbouring cities and municipalities.

Assuming that the development of public transport is a basic and priority vehicle reduction tool for the purposes of this article, an analysis of the plans for sustainable development of public transport (Table 4) has been carried out.

Table 4

Conclusions from the analysis of the provisions of the plans for sustainable development of public transport in Warszawa, Krakow, Wroclaw and Poznan with regard to air protection

City	Conclusions from the analysis of provisions
Warszawa	Transportation is the main source of air pollution in Warszawa, actions aiming at the protection of the air and water quality are necessary – via exchange of public transport rolling stock, for vehicles that significantly reduce CO, NMHC, NO_x, PM emissions [22].
Krakow	The main source of air pollution in Krakow is the emission from the combustion of coal and its derivatives in individual sources of heat. Transport, which in turn is the primary source of NO_x emissions and contributes the largest share of this pollutant emissions, contributes to a lower degree of air pollution [23].
Wroclaw	The plan assumes that it will not radically improve the air pollution situation, but calming traffic in the metropolitan centre will result in significant reduction of emissions as traffic is expected to decrease by 11 % [7].
Poznan	The plan includes the introduction of restricted traffic areas and the exchange of public transport rolling stock, the development of bicycle lanes and the bicycle rental system. There is also a strong preference for public transport and non-motorised traffic and the introduction of the car traffic restrictions [24];

The assumptions recorded in the analysed documents allow us to conclude that significant improvements in air quality due to the development of public transport offer are expected in Warszawa and Poznan. The transport plan analysed for Krakow does not seem to perceive the role of transport in the generation of air pollutants despite the fact that Krakow is polluted the most among the analysed cities. In the case of Wroclaw, based on the simulations conducted, the plan assumes only a partial reduction of pollution.

Other instruments supporting the reduction of pollutant emissions into the atmosphere in urban systems and functional areas are needed. On the one hand, they must be legal instruments giving the possibility of establishing restricted zones in cities, on the other hand, principles of spatial planning regulating directions of development of settlement structures and guaranteeing the availability of society to services and various functions in space. The draft amendment to the Environmental Protection Act in 2017 contained a provision allowing for the creation of restricted traffic zones in the future, but it is not currently being proceeded. In this respect, a model to repeat may be the system of environmental zones (Ger.: Die Umweltzone, Eng.: low emission zone), which operate under Federal law of the Federal Republic of Germany – regulating the identification of motor vehicles with low pollutant load (Verordnung zur Kennzeichnung der Kraftfahrzeuge mit geringem Beitrag zur Schadstoffbelastung – 35. BImSchV). In the case of FRG, there are 55 zones in cities where the movement of cars equipped with engines with legally defined emission levels is restricted.

Recognised and used planning tool to reduce individual transport is Transit-oriented development (TOD), which is the development of urban structures based on stations and public transport stops. In this case, it is assumed to locate services and dwelling functions as well as business activities in the area accessible for pedestrians in an acceptable distance from the train station or tram or bus station. At the same time, this solution seeks to optimise the density of development and concentration of activities against the expansion of the development zone and the extensive use of space further away from the centres defined by public transport stations. This solution is known in the United States and Europe and has been used in various variants in the 19th and 20th century. [25] The main problem of using this solution in Polish cities is the atomisation of spatial development plans in cities after 1990, subsequent amendments to spatial development and planning laws, as a result of depriving the role of coordinating regional development plans and eventual legal separating of the planning of communication systems and spatial planning.

Mobility management as a tool in the context of improving air quality in urban agglomerations

The increasing demand of the population for mobility while limiting urban space forces them to move away from the traditional mobility model of their car to the use of multimodal solutions based on the combination of different transport modes. The challenge of modern and future cities will certainly be to manage the mobility of the public, not only by providing transport infrastructure and by introducing public transport, but also by developing other forms of transport such as car sharing, bike sharing, and autonomous vehicles. Access to various forms of transport and travel time optimisation will be possible thanks to the use and popularisation of GPS-based transport management systems. This is evidenced by modern trends in research conducted by IT companies in co-operation with transport business operators, both representing transport manufacturers and transport providers. Having access to a multimodal, non-emission transport system will replace the possession of an individual car. This is a vision that must be addressed not only by urban infrastructure managers but also by city planners, lawyers and businesses before opening up new transport capacity – optimising transfer, not offering a means of transport. The European Commission is currently discussing the shape of urban policy and its financial support and mobility management [26]. This justifies the fact that in the European Union more than 75 % of the population lives in urban areas – cities and their functional areas. With the upward trend, it is expected to multiply the problems arising from transport congestion and the danger of exceeding air quality standards. Officially supported new transport systems that are elements of managed mobility could be:

– Car sharing system – a form of service consisting of providing – renting a car that can replace the use of private cars;

– Car-pooling/ride sharing – travel forms consisting in sharing a place in your own car with a person or people travelling in the same direction.

Travel plans – plans developed by mobility organisations (work establishments, schools, universities and others) with a view to optimising the time, cost and the use of transport forms of people with the minimal use of personal transport.

Information systems based on data analysis of available means of transport to travel to a user-specified destination. Due to the widespread use of mobile data transmission and processing equipment, these systems are currently in a dynamic development phase.

Mobility management can, therefore, be seen as a necessity of civilisation advancement and changes in the development of the economy [27]. It is one of the instruments to reduce negative impacts on the climate and to reduce greenhouse gases, and in a significant way, it can bring measurable benefits in the short run in the context of the reduction of linear air pollutants generated by car traffic.

Summary and conclusion

The analyses carried out in this study showed that in the years 2010–2015 in the analysed cities: Poznan, Wroclaw, Krakow and Warszawa there were increased levels of air pollution. Particularly high concentrations were observed for the suspended particulate matters of PM10 and PM2.5. The highest concentrations of all urban agglomerations occurred in Krakow.

It is significant that vastly higher concentrations of pollutants occurred at traffic stations. The clearest differences in concentration levels between types of measurement stations were found for NO_x and NO_2. In addition, at traffic stations, pollutant concentrations remained at a similar level throughout the year, while in the case of background stations, concentrations were higher in the autumn and winter seasons. These dependencies demonstrate the significant influence of mobile emissions on air quality in urban agglomerations. It is significant that mobile sources contribute to the occurrence of episodes of high concentrations of dust pollution (PM10 and PM2.5), but also gas pollutions (NO_x and NO_2), which may endanger the health of the residents.

Therefore, the impact of mobile sources on air quality should be taken into account in urban planning, and measures should be taken to eliminate or reduce the risks arising therefrom. Among the instruments that reduce the emission of air pollutants into the air are certainly urban rules, which assume the correlation of the development of settlement structures with existing communication lines and increase the accessibility for the society to complementary forms of transport together with the development of public transport.

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WPŁYW TRANSPORTU NA JAKOŚĆ POWIETRZA W WYBRANYCH MIASTACH POLSKI

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Abstrakt: Transport drogowy staje się coraz bardziej znaczącym źródłem emisji zanieczyszczenia powietrza. W ciągu najbliższych kilku dekad transport drogowy stanie się istotnym czynnikiem przyczyniającym się do zanieczyszczenia powietrza w miastach europejskich. W Polsce według Krajowego Ośrodka Bilansowania i Zarządzania Emisjami (KOBiZE) ditlenek i tlenek węgla (CO_2 i CO), tlenki azotu (NO_x), niemetanowe lotne związki organiczne (NMLZO) i pył są głównie emitowane z transportu. Głównym celem artykułu było określenie zmienności stężeń CO, NO_2, NO_x, O_3, PM10 i PM2.5 w latach 2010–2015 w wybranych polskich miastach (Poznań, Wrocław, Kraków i Warszawa). Analiza wskazuje, że miasta te mają przede wszystkim problem z zanieczyszczeniem powietrza cząstkami stałymi (PM), podczas gdy dla pozostałych zanieczyszczeń takich jak CO, NO_2, NO_x, O_3 poziomy ustalone dla ochrony zdrowia nie były przekraczane. Ponadto stężenia zanieczyszczeń było wyższe na stacjach komunikacyjnych niż na stacjach tła miejskiego. Spośród analizowanych miast najwyższe stężenia były rejestrowane w Krakowie.

Słowa kluczowe: transport drogowy, jakość powietrza, polskie miasta, pył zawieszony, zanieczyszczenia gazowe