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SEASONAL VARIABILITY OF TROPOSPHERIC OZONE CONCENTRATION IN CHOSEN LOCALITIES OF NORTH-WESTERN POLAND SHAPED BY METEOROLOGICAL CONDITIONS

ROBERT KALBARCZYK, ELIZA KALBARCZYK

Department of Meteorology and Climatology, West Pomeranian University of Technology, Papieża Pawła VI 3, 71-469 Szczecin, Poland; e-mail: Robert.Kalbarczyk@zut.edu.pl

Abstract

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The aim of the paper was to recognize the temporal structure of tropospheric ozone in chosen localities of north-western Poland in connection with meteorological conditions. The basis for the study was constituted by the 24-hour concentration values of O_3 and 24-hour data of five meteorological elements in the period from 1st May 2005 to 30th April 2007, coming from three stations of State Monitoring of the Environment (from Szczecin, Widuchowa and Gorzów Wielkopolski), located in the neighbourhood of the Polish–German border in north-western Poland. The relation between O_3 concentration and chosen meteorological elements was studied by means of correlation and regression analysis during the four climatic seasons of Poland: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). In the climatic conditions of north-western Poland, on average the highest concentration of tropospheric ozone amounting 68.8 $\mu g.m^{-3}$, occurred in the spring season (March–May), and the lowest, reaching 32.0 $\mu g.m^{-3}$ – in the winter season (November–February), and it was the highest in Widuchowa station, and in Gorzów Wielkopolski – the lowest. Out of meteorological elements analyzed, explicitly unfavourable influence on the clearness of atmosphere had an increase in the amounts of solar radiation, air temperature and wind speed, and a decrease in air humidity. The largest coefficients of determination of multiple regression equations, describing the relation between tropospheric ozone concentration and meteorological elements, were obtained in the autumn season and they ranged from 66.0% in Szczecin station to 82.3% in Gorzów Wielkopolski station.

Key words: air pollution, correlation and regression analysis, weather

Introduction

In the recent years tropospheric ozone, due to its growth of concentration dangerous for a human and the environment, has become one of the main research problems of the

atmospheric chemistry. More and more numerous papers document its harmful impact on phytocoenosis and a human (Maňkovská et al., 1999, 2002; Manning et al., 2002; Bytnerowicz et al., 2003). Ozone in the troposphere comes from the natural sources (mainly from the ozone layer – lower stratosphere and natural photochemical reactions with the participation of nitric oxide NO_x of natural origin and natural non-metallic hydrocarbons – isoprene and terpens, some small quantities are also the result of electric discharges in the air during thunderstorms) and anthropogenic (as a result of chemical ozone production processes producing ozone by photolysis of nitrogen dioxide, in the presence of carbon oxide and carbohydrates, substances of mostly anthropogenic origin). Favourable for ozone formation are high temperature, high insolation and low relative humidity of the air (Ośródka, Święch-Skiba, 1997; Davis et al., 1998; Treffeisen, Halder, 2000; Walczewski, 2005). Concentration of tropospheric ozone is characterized by explicit daily and yearly variability, depending on the latitude, local field and meteorological conditions and the distance form the sources of air pollution emissions and the time of their movement (Davis et al., 1998; Baur et al., 2004; Lehman et al., 2004; Elminir, 2005; Mazzeo et al., 2005). In the direct vicinity of linear sources of pollution (streets, highways) ozone concentration is very low, and during the periods of the occurrence of ozone smog the concentration of ozone in the city can be even lower than in adjacent rural areas, especially the ones situated on the leeward side of the agglomeration (Godłowska, 2004; Godłowska, Tomaszewska, 2006). In north-western Poland ozone concentrations excess the upper assessment threshold both in Szczecin Agglomeration and in the remaining area (Landsberg-Uczciwek et al., 2007).

The aim of the paper was to recognize the temporal structure of tropospheric ozone in chosen localities of north-western Poland in connection with meteorological conditions.

Material and methods

The basis for the study was constituted by the 24-hour concentration values of O_3 and 24-hour data of meteorological elements: the amount of total radiation, the average air temperature, the relative air humidity, atmospheric pressure and wind speed in the period from 1st May 2005 to 30th April 2007, coming from three stations of State Monitoring of the Environment (from Szczecin, Widuchowa and Gorzów Wielkopolski), located in the neighbourhood of the Polish–German border in north-western Poland (Fig. 1).

The measurement of ozone in the imission stations: Szczecin, Widuchowa and Gorzów Wielkopolski was done by the use of MLU 400E analyzer manufactured by Monitor Labs company. The measurement principle of the analyzer is based on the absorption of UV radiation due to the inner resonance of O_3 molecules.

The relation between O_3 concentration and the course of particular meteorological elements was studied by means of correlation analysis in the four climatic seasons of Poland: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

On the other hand, for the separation of a complex of meteorological elements significantly influencing the concentration value of O_3 the multiple regression analysis with the use of stepwise forward regression method was applied, with the assumed level of $\alpha \leq 0.05$.

As a measure of adjustment of regression function to empirical data, the coefficient of determination was applied (R^2, in %).

Station	No.	λ	ϕ	Elevation [height above sea level]	Station type
Szczecin	1	14°39'	53°22'	10	urban background
Widuchowa	2	14°23'	53°17'	2	regional background
Gorzów Wielkopolski	3	15°13'	52°44'	22	urban background

Fig. 1. Distribution and characteristics of State Monitoring of the Environment stations conducting the measurements of tropospheric ozone concentration in north-western Poland.

Results and discussion

Characteristics of meteorological conditions

In the period analyzed lasting form 1st May 2005 to 30th April 2007, the average 24-hour amount of solar radiation in north-western Poland worked out 55.2 W.m^{-2} and ranged from 39.0 W.m^{-2} in Szczecin to 67.1 W.m^{-2} in Gorzów Wielkopolski, while the biggest was recorded in the summer season (from 69.3 to 122.9 W.m^{-2}), and the smallest – in the winter season (from 9.4 to 20.9 W.m^{-2}) (Table 1). In the spring the amounts of solar radiation were bigger than in the autumn, from two times in Szczecin to more than 2.5 times in Gorzów Wielkopolski spring predominance of solar insolation over the autumn one in this part of Poland was stated, among others, by Kalbarczyk et al. (2006). The average yearly air temperature was 8.5 °C and ranged from 8.3 °C in Szczecin to 8.9 °C in Widuchowa, and during the seasons the extreme values were -1.1 °C in the winter and 18.0 °C in the summer, both in Gorzów Wielkopolski in spring the average daily air temperature was visibly lower, on average by 2.7 °C, than in autumn, which is quite the reverse than in the case of solar radiation amounts.

The average yearly relative air humidity in north-western Poland was 75.2%, from 72.9% in Gorzów Wielkopolski to 77.8% in Szczecin. The distribution of relative air humidity was quite the opposite to the course of average air temperature, because the highest air humidity

T a b l e 1. Average 24-hour values of chosen meteorological elements.

Meteorological element	Station	Season				year (Jan.–Dec.)
		spring (March–May)	summer (June–Aug.)	autumn (Sept.–Nov.)	winter (Dec.–Feb.)	
RAD [W.m^{-2}]	Szczecin	51.5	69.3	25.9	9.4	39.0
	Widuchowa	80.6	101.3	36.5	19.1	59.4
	Gorzów Wielkopolski	90.5	122.9	34	20.9	67.1
TP [^{0}C]	Szczecin	7.3	17.1	9.6	-0.9	8.3
	Widuchowa	7.0	17.8	10.3	0.3	8.9
	Gorzów Wielkopolski	7.0	18.0	9.5	-1.1	8.4
RH [%]	Szczecin	70.3	66.9	82.8	91.0	77.8
	Widuchowa	69.3	67.1	78.2	84.6	74.8
	Gorzów Wielkopolski	67.3	60.4	79.0	84.8	72.9
PH [hPa]	Szczecin	1009.9	1010.3	1011.6	1011.5	1010.8
	Widuchowa	1003.6	1003.9	1004.6	1005.0	1004.3
	Gorzów Wielkopolski	1006.8	1007.4	1006.6	1008.5	1007.3
WS [m.s^{-1}]	Szczecin	1.4	1.1	1.4	1.9	1.5
	Widuchowa	1.6	0.9	1.3	2.1	1.5
	Gorzów Wielkopolski	0.7	0.6	0.5	0.9	0.7

Notes: RAD – total solar radiation, TP – mean air temperature, RH – air humidity, PH – air-pressure, WS – mean wind speed

was observed in the winter season, (from 84.6% in Widuchowa to 91.0% in Szczecin), and the lowest in the summer season (from 60.4% in Gorzów Wielkopolski to 67.1% in Widuchowa). According to Czarnecka et al. (2004) thermal and humidity air conditions in this part of Poland are shaped mainly under the influence of polar maritime air masses advection, and the vicinity of the Baltic sea plays a significant role here. Apart from circulatory factors, also physiographic conditions have a great impact, especially terrain relief, its forestation and number of lakes. An average atmospheric pressure was 1007.5 hPa and ranged from 1004.3 hPa in Widuchowa to 1010.8 hPa in Szczecin. The difference in the pressure value between the seasons analyzed was rather slight, from 1.4 hPa in Widuchowa to 1.9 hPa in Gorzów Wielkopolski. On the other hand, an average wind speed for the stations analyzed was 1.2 m.s^{-1}, and varied from 0.7 m.s^{-1} in Gorzów Wielkopolski to 1.5 m.s^{-1} in Szczecin and Widuchowa, while the biggest was recorded in the winter season (from 0.9 to 2.1 m.s^{-1}), and the smallest – in the summer season (from 0.6 to 1.1 m.s^{-1}).

Time structure of O_3 concentration

The average yearly concentration of tropospheric ozone in north-western Poland in the period form 1st May 2005 to 30th April 2007 was 51.9 µg.m^{-3} and ranged from 42.4 µg.m^{-3} in

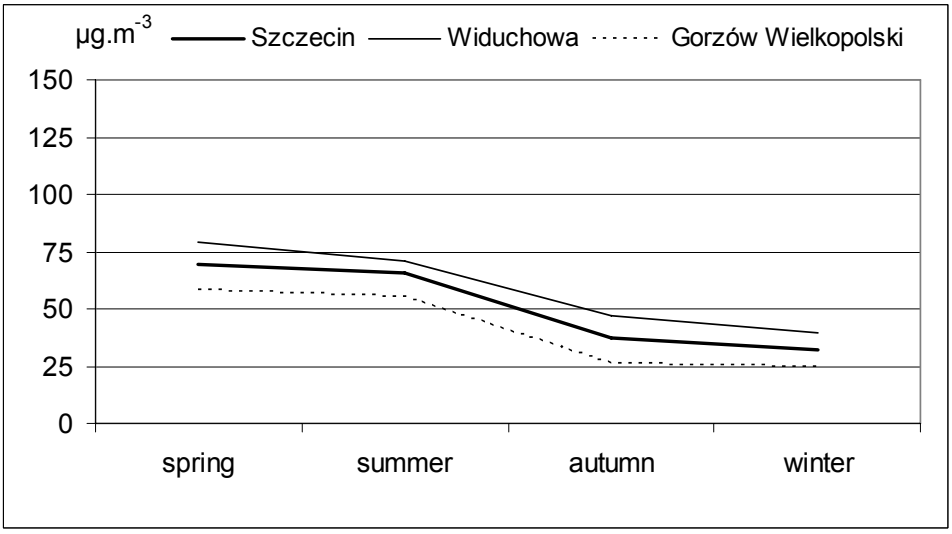


Fig. 2. Average seasonal concentration (µg.m^{-3}) of tropospheric ozone.

Gorzów Wielkopolski to 61.1 µg.m^{-3} in Widuchowa. In all the stations examined the highest concentration of O_3 was recorded in the spring season – in Gorzów Wielkopolski 58.0 µg.m^{-3}, in Szczecin 69.5 µg.m^{-3}, in Widuchowa 79.0 µg.m^{-3}, and the lowest in the winter season – respectively 24.5, 31.9 and 39.7 µg.m^{-3} (Fig. 2). Similar results concerning the value and temporal distribution of O_3 concentration in four measuring stations located in different regions of Poland were obtained by Bogucka (2006), according to whom the highest concentrations occur usually in the spring. In Szczecin and Gorzów Wielkopolski the average highest concentration of O_3 occurred in July, in Widuchowa – in April, on the other hand, the average lowest concentration of O_3, in November and December respectively (Fig. 3).

Figures 4 and 5 show some statistical characteristics describing temporal variability of O_3 concentration according to the consecutive months of the year. The highest absolute maximums of ozone immission were recorded in Widuchowa, where they ranged from 63.0 µg.m^{-3} in December to 141.0 µg.m^{-3} in May, and the lowest were in Gorzów Wielkopolski – from 44.0 µg.m^{-3} in October to 117.0 µg.m^{-3} in May; in Szczecin they were respectively 119.0 µg.m^{-3} in July and 62.0 µg.m^{-3} in December (Fig. 4). The average absolute minimum for the stations considered was more than 4 times lower than the average maximum. Absolute minimum was recorded in Gorzów Wielkopolski – in December (1.0 µg.m^{-3}), while in Szczecin – in January, November and December (4.0 µg.m^{-3} each month), and in Widuchowa – in January and December (6.0 µg.m^{-3} each).

An average yearly lower quartile value for O_3 concentration ranged from 30.9 µg m^{-3} in Gorzów Wielkopolski to 48.8 µg.m^{-3} in Widuchowa, while in Gorzów Wielkopolski developed within the limits from 5.0 µg.m^{-3} in November to 53.0 µg.m^{-3} in June, in Szczecin from 16,3 µg.m^{-3} in

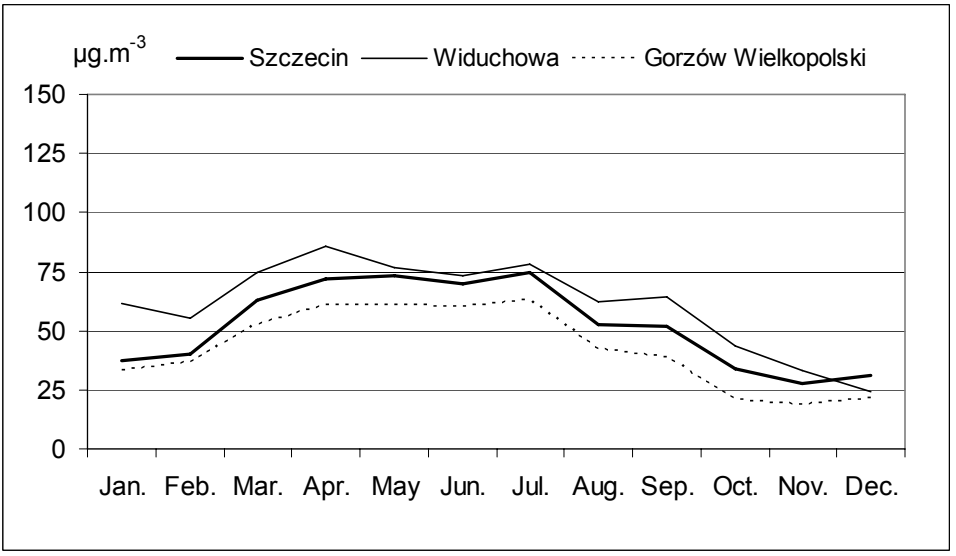


Fig. 3. Average monthly concentration (µg.m^{-3}) of tropospheric ozone.

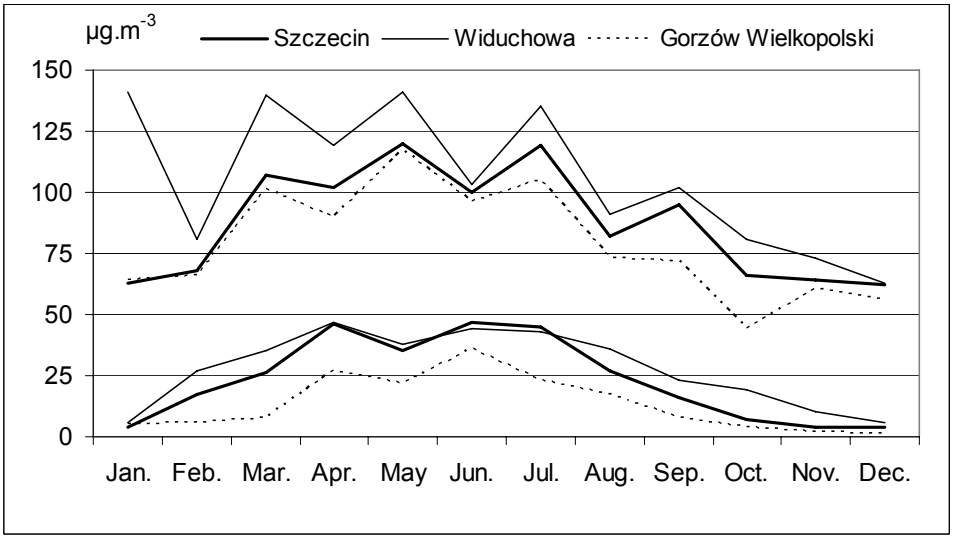


Fig. 4. Absolute maximum and minimum concentration (µg.m^{-3}) of tropospheric ozone.

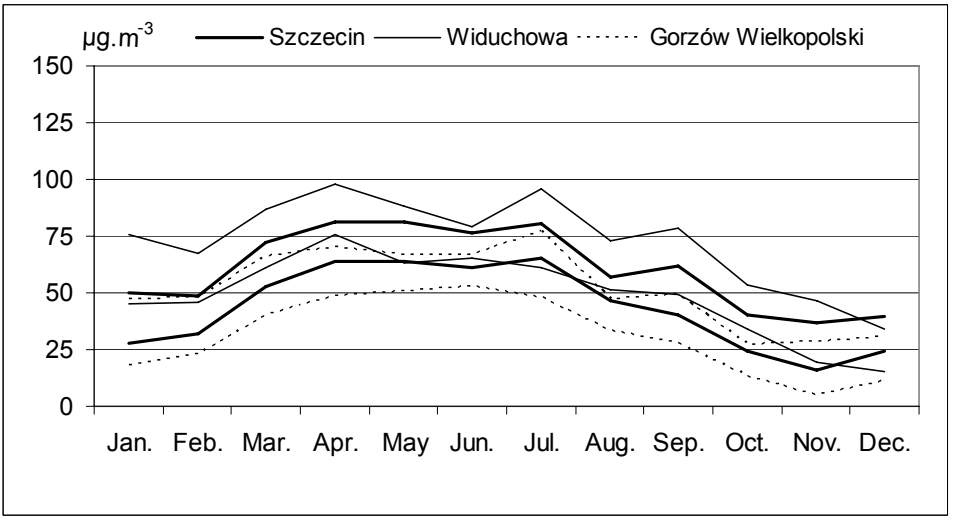


Fig. 5. Lower and upper quartile of tropospheric ozone concentration (µg.m^{-3}).

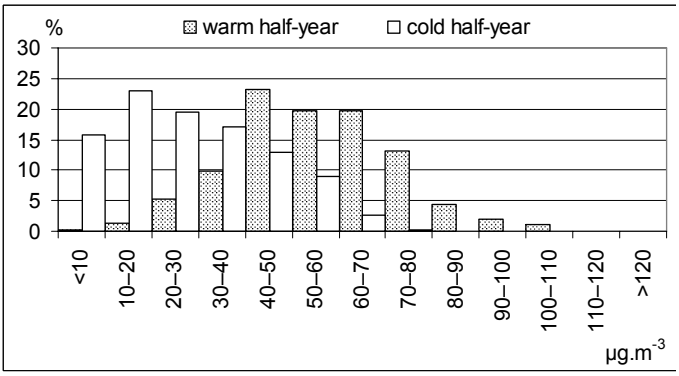
November to 65.0 µg.m^{-3} in July and in Widuchowa from 15.0 µg.m^{-3} in December to 75.5 µg.m^{-3} in April (Fig. 5). An average upper quartile value was higher than the lower quartile on average by 50%, the biggest difference between the quartile occurred in Gorzów Wielkopolski station (70%), while the smallest – in Szczecin station (40%). The highest upper quartile value for O_3 concentration was appointed in Widuchowa station in April and it reached 97.8 µg.m^{-3}, while the lowest – in Gorzów Wielkopolski station in October and it was 27.0 µg.m^{-3}.

Frequency diagrams (Fig. 6) of 24-hour O_3 concentrations within the established value ranges in the two half-year terms analyzed, showed that during the warm half-year (from March to August) the majority of the results obtained fell into the range from 40 to 50 µg.m^{-3} in Gorzów Wielkopolski (23.2%), from 50 to 60 µg.m^{-3} in Szczecin (24.6%) and from 60 to 70 µg.m^{-3} in Widuchowa (23.1%), while during the cold half-year (from September to February) – respectively from 10 to 20 µg.m^{-3} in Gorzów Wielkopolski (22.9%), from 30 to 40 µg.m^{-3} in Szczecin (29.5%) and from 40 to 50 µg.m^{-3} in Widuchowa (19.5%). In all the stations under analysis, in over 75% (from 75.8% in Gorzów Wielkopolski to 78.6% in Widuchowa), in the warm half-year O_3 concentrations were contained in the range from 40 to 80 µg.m^{-3} and in more than 72% (from 72.7% in Widuchowa to 87.7% in Szczecin) in the cold half-year – from 10 to 60 µg.m^{-3}.

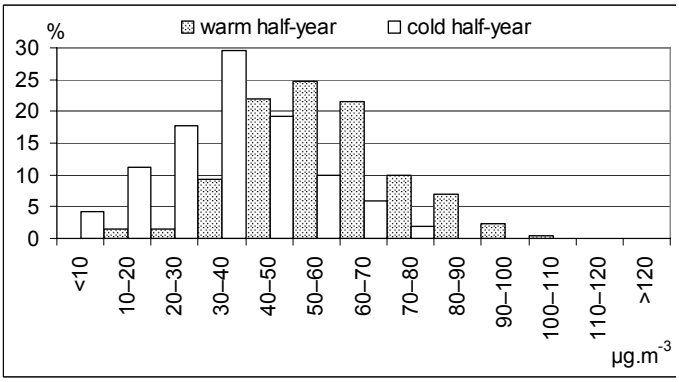
Impact of meteorological conditions on O_3 concentration

Correlation analysis of tropospheric ozone concentration values and chosen meteorological elements proved that the greatest number of statistically important relations was stated

Szczecin



Widuchowa



Gorzów Wielkopolski

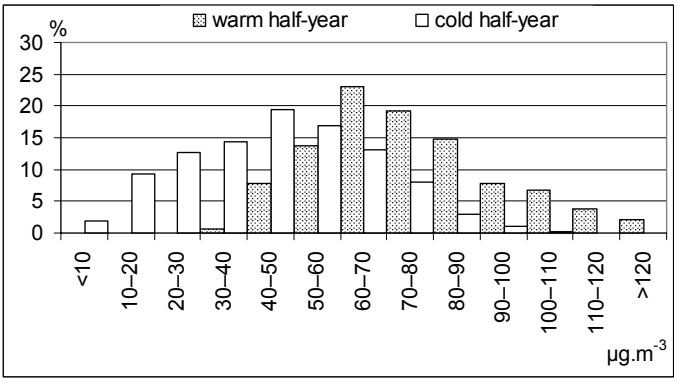


Fig. 6. Frequency (%) of occurrence of 24-hour concentrations (µg.m) of tropospheric ozone in the ranges established.

T a b l e 2. Significant coefficients of determination (%) for the relations between tropospheric ozone concentration and chosen meteorological elements.

Meteorological element	Station	Season			
		spring (March–May)	summer (June–Aug.)	autumn (Sept.–Nov.)	winter (Dec.–Feb.)
RAD [W.m^{-2}]	Szczecin	(+) 5.1***	(+) 10.4***	(+) 29.3***	(+) 3.4***
	Widuchowa			(+) 34.1***	(+) 9.6***
	Gorzów Wielkopolski	(+) 13.1***	(+) 28.4***	(+) 23.9***	(+) 4.3***
TP [^{0}C]	Szczecin	(+) 4.8***	(+) 33.9***	(+) 32.2***	(+) 6.9***
	Widuchowa		(+) 69.5***	(+) 42.2***	
	Gorzów Wielkopolski	(+) 3.7***	(+) 7.8***	(+) 19.8***	(+) 1.7***
RH [%]	Szczecin	(-) 25.5***	(-) 35.3***	(-) 50.6***	(-) 6.5***
	Widuchowa	(-) 10.7***	(-) 56.2***	(-) 64.2***	(-) 29.4***
	Gorzów Wielkopolski	(-) 34.3***	(-) 41.2***	(-) 47.2***	(-) 15.7***
PH [hPa]	Szczecin				(-) 6.7***
	Widuchowa	(+) 3.7**			
	Gorzów Wielkopolski	(+) 8.8***	(+) 4.6***		(-) 4.7***
WS [m.s^{-1}]	Szczecin			(+) 4.7***	(+) 30.4***
	Widuchowa			(+) 7.8***	(+) 7.6***
	Gorzów Wielkopolski	(+) 6.4***	(+) 6.2	(+) 34.5***	(+) 41.6***

Notes: *** significant at $\alpha \leq 0.01$, ** significant at $\alpha \leq 0.05$, direction of dependence given in the brackets, other explanations, see Table 1

in Gorzów Wielkopolski station, the smallest in Widuchowa (Table 2). In all the stations and seasons considered (spring, summer, autumn, winter), solar radiation had a significant influence on O_3 concentration, with the exception of spring and summer in Widuchowa station. The increase in solar radiation contributed into the growth of O_3 concentration, and the closest relation was proved in the autumn in the stations of Widuchowa (R^2 = 34.1%) and Szczecin (R^2 = 29.3%), and in the summer – Gorzów Wielkopolski (R^2 = 28.4%). As a result of solar radiation impact, and more precisely, a part of its spectrum with the wave length shorter than 400 nm, due to the photolysis there is a decomposition of nitric dioxide, which as a consequence leads to ozone formation (Ośródka, Święch-Skiba, 1997). The increase in the average air temperature in all the stations and seasons, explicitly contributed into the growth of O_3 concentration, with the exception of spring and winter seasons in Widuchowa station, for which it was not possible to statistically prove that relation. The closest correlation in Widuchowa (R^2 = 69.5%) and in Szczecin (R^2 = 33.9%) was proved in the summer, and in Gorzów Wielkopolski (R^2 = 19.8%) – in the autumn. Strong dependence of tropospheric ozone concentration on air temperature was confirmed, among others, by Ośródka and Święch-Skiba (1997), Treffeisen and Halder (2000), and Elminir (2005). The correlation between O_3 concentration and air humidity revealed only the positive role of this element in the processes of self-purification of the atmosphere. Coefficients of determination for this dependence were very high, especially in the summer and in the autumn,

and they ranged from 35.3 to 64.2%. In the spring, air humidity determined the value of concentration of the characterized pollution from approximately 11% in Widuchowa to over 34% in Gorzów Wielkopolski, while in the winter – from approximately 7% in Szczecin to over 29% in Widuchowa. In Elminir's research (2005) the highest average ozone concentration was found out with the low relative air humidity ≤ 40%. According to Ośródka and Święch-Skiba (1997), the increase in air humidity may cause the elimination of ozone from the atmosphere by the reaction of this gas with water.

In the spring and summer seasons, atmospheric pressure correlated positively with the immission of O_3, while in the winter season – negatively. Similar results were obtained by Godłowska (2004), according to whom an increase in atmospheric pressure in the summer period may cause an increase in ozone concentration, and in the winter period – a decrease. The strongest influence of barometric conditions, proved in as many as three seasons except for the autumn one, appeared in Gorzów Wielkopolski station. Strong relations between ozone concentration and anticyclone weather were demonstrated, among others, by Davis and others (1998), and Godłowska and Tomaszewska (2006). Correlation analysis of O_3 concentration and wind speed revealed only the negative role of this element. The increase in average O_3 concentrations with the increase of wind speed may be caused by the fact that sources of pollution located in some distance from the measuring station have a significant influence on the immission registered (Walczewski, 2000; Treffeisen, Halder, 2000). Godłowska's analysis (2004) also proves that in the summer period the increase in wind speed determines the higher concentration of O_3. The impact of wind speed on O_3 concentration was the biggest in the winter, and then in the autumn. The closest dependence was proved in the winter season, R^2 was 41.6% in Gorzów Wielkopolski station.

Multiple regression analysis makes it possible to select the most important meteorological elements out of the entire complex of the ones significantly influencing the seasonal variability of tropospheric ozone concentration in north-western Poland (Table 3). The results were presented in the form, which allows the reconstruction of the equation in its full form. For this purpose – apart from coefficients of multiple regression – for meteorological elements also the numerical value of a intercept constituting an integral part of regression equation was given. Out of 12 regression equations built, in 6 of them three independent variables were found in each one, in 5 of them – two, and in 1 equation – one variable. Data included in Table 3 show that the best results concerning the description of variability of O_3 concentration by meteorological elements were obtained in the autumn season, R^2 ranged from 66.0% in Szczecin to 82.3% in Gorzów Wielkopolski, and then in the summer season, in which R^2 ranged from 50.7% in Szczecin to 72.6% in Widuchowa. Definitely worse results were obtained in the spring and winter season in Widuchowa and in the spring season – in Szczecin. Out of five meteorological elements considered, air humidity and wind speed were the ones that most frequently decided about the value of ozone concentration, while the average air temperature and solar radiation – significantly more seldom. Air humidity in the complex of meteorological elements had a significant, negative impact on O_3 concentration in all the stations and seasons except for Gorzów Wielkopolski in the summer season. The analysis of regression equations coefficients demonstrates that

T a b l e 3. Intercept and coefficients of a multiple regression equation for the relations between tropospheric ozone concentration and chosen meteorological elements.

Season	Station	Intercept	Regression coefficient for meteorological elements					R2 [%]
			RAD [W.m^{-2}]	TP [^{o}C]	RH [%]	PH [hPa]	WS. [m.s^{-1}]	
	Szczecin	108.225***			-0.629***		4.355***	30.5
Spring	Widuchowa	120.988***			-0.589***			10.7
(March–May)	Gorzów Wielkopolski	99.465***			-0.7705***		13.223***	41.9
	Szczecin	60.324***		2.041004***	-0.5506***		6.4092***	50.7
Summer	Widuchowa	41.3039***		3.388***	-0.454***			72.6
(June–Aug.)	Gorzów Wielkopolski	-3.829**		2.883***			12.5047***	55.7
	Szczecin	95.968***		1.008105***	-0.934***		6.5701***	66.0
Autumn	Widuchowa	125.822***		1.35009***	-1.251***		4.587***	71.0
(Sept.–Nov.)	Gorzów Wielkopolski	46.697***		1.0921***	-0.579***		26.911***	82.3
	Szczecin	45.8107***	0.784***		-0.367***		8.753***	49.2
Winter	Widuchowa	122.6508***	0.466***		-1.0732***		2.7081***	34.9
(Dec.–Feb.)	Gorzów Wielkopolski	68.292***			-0.619***		16.379***	50.1

Notes: R^2 – determination coefficient, other explanations, see Table 1 and 2

the amount of O_3 immission was most strongly determined by air humidity in the autumn season, and most weakly – in the summer.

On the other hand, wind speed in the complex of meteorological elements, just like in the correlation analysis, had a significant positive impact, except for the spring and summer seasons in Widuchowa station, the biggest in the autumn, then in the winter. Wind and relative humidity as the most important meteorological element shaping air pollution was pointed out by Elminir (2005). Air temperature as an independent variable entered the model only in two seasons – summer and autumn, while solar radiation in one – winter. The researchers did not manage to confirm the impact of atmospheric pressure in the complex of meteorological elements by means of constructed regression equations, in spite of some significant relations between this element and O_3 concentration discovered earlier (Table 2).

On the basis of multiple regression equations contained in Table 3, average 24-hour values of meteorological elements accompanied by a higher than the average level of O_3 concentration were determined. The thesis assumptions were that the increased value of O_3 concentration constituted 110% of the average, calculated separately for a given station and season. In the spring, a higher than the average level of O_3 occurred in north-western Poland, when air humidity was on average lower than 59%, in Szczecin < 60.3%, in Widuchowa < 57.3% and in Gorzów Wielkopolski < 58.9% and wind speed > 2.8 and 1.2 m.s^{-1}, in Szczecin and Gorzów Wielkopolski respectively (Table 4). In the summer 110% of the average O_3 concentration was recorded when the average air temperature varied above from 19.7 to 20.3 ^{o}C, air humidity below 51.7–55.1% and wind speed above 1.0–2.1 m.s^{-1}. In the autumn, a higher than the average level of ozone concentration occurred when air temperature exceeded 13.4 ^{o}C in Szczecin and Widuchowa and 12.5 ^{o}C in Gorzów Wielkopolski, and air

T a b l e 4. Average 24-hour values of meteorological elements determined in the average conditions. Taken into consideration in multiple regression equations Table 3 in which an increased level (110% of a mean in a given locality and season) of tropospheric ozone concentration occurs.

Season	Station	Meteorological element				
		RAD [W.m-2]	TP [0C]	RH [%]	PH [hPa]	WS. [m.s-1]
Spring (March – May)	Szczecin			< 60.3		> 2.8
	Widuchowa			< 57.3		
	Gorzów Wielkopolski			< 58.9		> 1.2
Summer (June–Aug.)	Szczecin		> 20.3	< 55.1		> 2.1
	Widuchowa		> 19.9	< 51.7		
	Gorzów Wielkopolski		> 19.7			> 1.0
Autumn (Sept.–Nov.)	Szczecin		> 13.4	< 78.7		> 2.0
	Widuchowa		> 13.4	< 74.8		> 2.2
	Gorzów Wielkopolski		> 12.5	< 73.4		> 0.6
Winter (Dec.–Feb.)	Szczecin	> 13.5		< 82.3		> 2.3
	Widuchowa	> 28.1		< 80.7		> 3.6
	Gorzów Wielkopolski			< 80.6		> 1.1

Note: explanations, see Table 1

humidity and wind speed were respectively < 78.7% and > 2.0 °C in Szczecin, < 74.8% and > 2.2 °C in Widuchowa, and < 73.4% and > 0.6 °C in Gorzów Wielkopolski In the winter the increased level of O_3 was accompanied by air humidity below 80.6–82.3%, solar radiation above 13.5 and 28.1 $W.m^{-2}$, and wind speed above 1.1–3.6 $m.s^{-1}$.

Table 5 contains the frequency of exceedence of meteorological elements' determined values accompanied by a higher than the average O_3 level. Air humidity conducive to an increased O_3 level close to the earth surface, occurred most often in the autumn (from 29.1% in Gorzów Wielkopolski to 32.8% in Szczecin), and the most seldom – in the summer (from 11.3% in Widuchowa to 19.8% in Szczecin). On the other hand, wind speed as one of two elements most strongly influencing ozone concentration, most frequently occurred in the winter (from 12.1 to 44.0%), and then in the autumn (from 16.0 to 35.6%), more seldom – in the spring (from 11.2 to 14.5%) and summer (from 12.0 to 13.6%). The determined values of wind speed in Szczecin and Gorzów Wielkopolski occurred over 2–3-times more often in the autumn and winter than in the spring and summer. Air temperature which also determined a higher than the average level of O_3 concentration, occurred with a similar frequency both in the summer (from 24.3 to 34.9%), and in the autumn (from 25.7 to 29.7%). The simultaneous occurrence of the determined values of several meteorological elements which were taken into consideration in multiple regression equations (Table 3) happened rather seldom and ranged from 0.6 to 6.4%; on average the most frequently – in the autumn (from 2.3 to 6.4%), in Gorzów Wielkopolski – in the winter (6.3%), and in Widuchowa – in the summer (5.3%).

T a b l e 5. Frequency (%) of occurrence of average 24-hour values of meteorological elements determining an increased level (110% of a mean in a given locality and season) of tropospheric ozone concentration.

Season	Station	Meteorological element					
		RAD [W.m^{-2}]	TP [^{0}C]	RH [%]	PH [hPa]	WS [m.s^{-1}]	for all significant elements
	Szczecin			22.4		11.2	0.7
Spring	Widuchowa			19.7			-
(March–May)	Gorzów Wielkopolski			29.0		14.5	4.1
	Szczecin		24.3	19.8		13.6	1.1
Summer	Widuchowa		32.3	11.3			5.3
(June–Aug.)	Gorzów Wielkopolski		34.9			12.0	1.7
	Szczecin		28.7	32.8		25.3	2.3
Autumn	Widuchowa		29.7	30.3		16.0	5.1
(Sept.–Nov.)	Gorzów Wielkopolski		25.7	29.1		35.6	6.4
	Szczecin	21.1		15.4		36.0	0.6
Winter	Widuchowa	20.4		27.4		12.1	0.6
(Dec.–Feb.)	Gorzów Wielkopolski			26.1		44.0	6.3

Note: explanations, see Table 1

Conclusion

In the climatic conditions of north-western Poland, on average the highest concentration of tropospheric ozone amounting 68.8 μg.m^{-3}, occurred in the spring season (March–May), and the lowest, reaching 32.0 μg.m^{-3} – in the winter season (November–February), and it was the highest in Widuchowa station, and in Gorzów Wielkopolski – the lowest .

More than 75% in the warm half-year (March–August) and 72% in the cold half-year (September–February) of 24-hour results of O_3 concentration contained in the range, respectively, from 40 to 80 and from 10 to 60 μg.m^{-3}. During the whole year in Gorzów Wielkopolski and Szczecin the most frequently registered results of O_3 concentration occurred in the range from 40 to 50 μg.m^{-3}, and in Widuchowa – from 50 to 60 μg.m^{-3}.

Most of significant relations between O_3 concentration and meteorological elements were proved in the winter season, especially in Szczecin and Gorzów Wielkopolski stations, while the smallest number of them – in the spring and summer season, especially in Widuchowa station.

Out of meteorological elements analyzed, explicitly unfavourable influence on the clearness of atmosphere had an increase in the amounts of solar radiation, air temperature and wind speed, and a decrease in air humidity.

The largest coefficients of determination of multiple regression equations, describing the relation between tropospheric ozone concentration and meteorological elements, were obtained in the autumn season and they ranged from 66% in Szczecin station to 82.3% in Gorzów Wielkopolski station.

Frequency of occurrence of 24-hour values of meteorological elements which were conducive to higher than average O_3 concentrations, ranged in north-western Poland on average from

19% in the spring season to 28% in the autumn season. On average in Gorzów Wielkopolski more often (almost 28%) than in Szczecin (over 22%) and Widuchowa (almost 22%).

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