AIR POLLUTION IN THE OLOMOUC CITY IN THE PERIOD 1991 – 2000

Miroslav VYSOUDIL, Martin JUREK

Abstract

The nature and trends of air pollution in the city of Olomouc between 1991 and 2000 are discussed. This was a period of fundamental structural economic changes in the Czech Republic. The spatial distributions of SO_2, NO_x, particulate matter and O_3 were studied, and an air quality index was assessed. The ambient air quality of the city is most seriously affected by NO_x emissions, for which traffic is considered to be the principal source. Limit values of SO_2 and particulate matter are exceeded only in the case of considerably worsened pollutant dispersion conditions. During the decade studied, there was stagnation or even a decrease in the emission of SO_2 and suspended particulate matter. In the case of NO_x and ground-level O_3, the trend cannot be described unambiguously. According to the values of the annual air quality index IKO_r (SO_2, NO_x and suspended particulate matter values assessed), it is possible to consider air quality as relatively good in the city of Olomouc over the whole period 1991 – 2000. Values of IKO_r were mostly between 1 and 2, which is interpreted as a suitable air quality.

Shrnutí

Znečištění ovzduší v Olomouci v období 1991 – 2000

Příspěvek popisuje charakter a vývoj znečištění ovzduší ve městě Olomouci v letech 1991 – 2000, tj v období výrazných transformačních ekonomických změn v České republice. Bylo sledováno časoprostorové rozložení SO_2, NO_x, prašného aerosolu, O_3 a byl stanoven index kvality ovzduší. Ovzduší města nejvíce zatěžují emise NO_x. Jejich hlavním zdrojem je silniční doprava. Imisní limity SO_2 a prašného spadu bývají překračovány jen při značně nepříznivých rozptylových podmínkách. Během sledovaného desetiletí lze na území města u SO_2 a polétavého prachu pozorovat stagnaci až pokles hodnot imisních koncentrací, u NO_x a O_3 nelze stanovit jednoznačný trend. Podle hodnot ročního indexu kvality ovzduší IKO_r (SO_2 – NO_x – polétavý prach) lze označit stav ovzduší v Olomouci v období 1991 – 2000 jako poměrně dobrý. Hodnota IKO_r se nejčastěji nacházela v intervalu < 1; 2), tj. vyhovující ovzduší, zdravé ovzduší.

Key words: *air pollution, air quality, SO_2, NO_x, suspended particulate matter, ground-level O_3, Olomouc, air quality index*

1. Introduction

Air quality reached much better parameters during the decade 1991 – 2000 in the whole of the Czech Republic. Olomouc is situated in central Moravia (eastern part of the Czech Republic – Fig. 1). The city and its surroundings had rated as relatively unaffected by pollution already before the year 1990. Today the situation is satisfactory and local industry cannot be considered a serious source of air pollution. Nonetheless, significant changes in air quality occurred within the period 1991 – 2000; the aim of this paper is to describe the extent and type of these changes.

The article is based upon the analysis of data available from air quality measurements in the city, also using the data published by ČHMÚ (Czech Hydrometeorological Institute – CHMI), database of OHES (Public Health Service of the District) and database of the Municipal Authority of Olomouc. Stanislav Kadlčík dealt in detail with the problem in his dissertation of 2002.

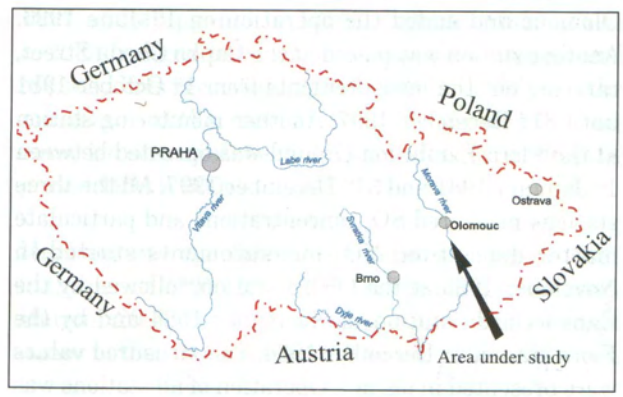

Fig. 1: Situation map

2. History of air quality monitoring in the Olomouc City

Monitoring of air pollution began in Olomouc in 1969 as a manual measurement of concentrations of sulphur dioxide (SO_2) and particulate matter deposition. The measurements were made regularly for one year in five-year periods.

Station	Location	Responsible entity	Way of monitoring	Measured pollutants
Flora	city centre, nearby a large park	HS	stationary – manual	SO_2, NO_X, SPM
Čapka Choda	western part of the city	HS	stationary – manual	SO_2, NO_X, SPM
OHES	southern and south-eastern part of the city	HS	stationary – manual	SO_2, NO_X, SPM
CHMI	northern part of the city, sports ground	CHMI	stationary – AMS	SO_2, NO, NO_2, CO, NO_X, SPM, PM10 + meteorological measurements
Šmeralova	central part of the city, by the students' hostels	CHMI	stationary – AMS-HM	SO_2, NO, NO_2, O_3, NO_X, PM10, heavy metals
City Hall	city centre, City Hall building	MAO	stationary – semiautomatic	SO_2, NO_X
Hotelový dům	southern and south-eastern outskirts, nearby a frequented road	MAO	stationary – semiautomatic	SO_2, O_3, NO_X
Hodolany	eastern outskirts of the city	MAO	stationary – semiautomatic	SO_2, NO_X

Tab. 1: Air pollution monitoring stations in the Olomouc City in the period 1991 – 2000

Notes: HS – Public Health Service of the district, CHMI – Czech Hydrometeorological Institute, MAO – Municipal Authority of Olomouc

The manual measurement of particulate matter deposition was carried out by the sedimentation method. Data were recorded in milligrams per litre per day. Sulphur dioxide (SO_2) measurement used the method of absorption. Data were recorded in milligrams per litre and then transformed into milligrams per day.

Continuous monitoring stations launched their operation in Olomouc in 1981. The first of them was placed at the Public Health Service of the District (OHES), starting measurements on 1st January 1981. In 1989 the station was moved into ZTS (Závody těžkého strojírenství) Olomouc and ended the operation on 1st June 1990. Another station was placed at the Čapka Choda Street, carrying out the measurements from 1st October 1981 until 31st December 1997. Another monitoring station at the Flora Exhibition Ground was operated between 1st January 1981 and 31st December 1997. All the three stations measured SO_2 concentrations and particulate matter deposition. NO_x measurements started in November 1983 at the OHES station, followed by the Čapka Choda station in November 1984 and by the Flora station in December 1984. The measured values were presented in $\mu g.\ m^{-3}$. Operation of all stations was guaranteed by OHES.

Two stations were established in 1994. The CHMI station began to work on 26th January 1994 and the station at the Šmeralova Street began its operation on 1st February 1994. On 1st January 1995, the network of air pollution monitoring stations in the city of Olomouc was added a station in the City Hall, another one at the Hotelový dům and the third one in the Hodolany quarter.

3. Sources of air pollution

Stationary sources are the most important sources of air pollution in the city of Olomouc. Emissions of all observed pollutants (SO_2, NO_x, particulate matter, CO and C_xH_y) decreased in the period 1991 – 1999. The most significant decrease was recorded for SO_2: 87.7 %. Particulate matter emissions decreased by 86.7 %, CO emissions by 84.5 % and NO_x emissions by 72.5 %.

Air pollution sources are categorised by REZZO (Register of Emissions and Air Pollution Sources) into four classes (REZZO 1 – Large pollution sources, output more than 5 MW; REZZO 2 – Medium-sized pollution sources, output between 0.2 and 5.0 MW; REZZO 3 – Small pollution sources, output less than 0.2 MW; REZZO 4 – Mobile emission sources). Contribution of the respective categories to aggregate emissions of observed pollutants is shown in tables 2 and 3 for the years 1991 and 1999. The decrease in emissions from large and medium-sized pollution sources was a result of various programmes aimed at air quality improvement (modernisation of production plants, combustion of gas and light fuel oil instead of coal). Another influence on air pollution came with the reduction programmes in industry. Small pollution sources showed a certain decrease in emissions particularly resulting from the substitution of coal with gas in local heating.

Large and medium-sized sources are significant for emissions of SO_2 a NO_x. Small pollution sources represent a major source of CO, solid particles and hydrocarbons (there were 21,250 households in Olomouc in 1991).

Category of sources	SO_2	NO_x	Solid particles	CO	C_xH_y
REZZO 1	9,535.85	2,098.43	2,325.57	10,870.87	95.36
REZZO 2	945.24	168.50	434.93	1,038.65	9.45
REZZO 3	3,567.30	1,337.74	1,640.90	5,493.60	35.67
Total	14,048.40	3,604.40	4,401.40	17,403.12	140.48

Tab. 2: Overall emissions (in tons per year) in the Olomouc City in 1991 by REZZO categories
(according to Study material of the Olomouc City for the layout of municipal air-quality monitoring stations, 1993)

Teplárna Olomouc (Heating Plant Olomouc) and Špičková výtopna Olomouc (Peak Heating Plant Olomouc) were the most important sources of air pollution in Olomouc within the category REZZO 1. In 1999 their contribution in total emissions (from categories REZZO 1–3) reached 58.3 % for SO_2, 56.5 % for NO_x, 6.5 % for solid particles, 1.6 % for CO, and 6.7 % for hydrocarbons. Corresponding shares in REZZO 1 emissions were 95.2 % for SO_2, 85.3 % for NO_x, 39.4 % for solid particles, 18.2 % for CO, and 24.4 % for hydrocarbons.

Other significant sources of emissions can be named, the most important of them being Milo S. P. Olomouc, Mora – Moravia a. s. Hlubočky, Moravské železárny (Moravian Ironworks) and Sigma Slévárny Lutín a. s. (Sigma Iron Foundries Lutín).

As to mobile emission sources, a direct connection between the growing intensity of traffic and the NO_x + CO concentration increase was demonstrated (Study material of the Olomouc city for the layout of municipal air-quality monitoring stations, 1993). Maximum values of concentrations correspond to the traffic rush hours, especially from 3 to 5 p. m.

The number of vehicles passing the streets may be used to describe the traffic intensity in the Olomouc City. Traffic in some busy roads was observed, showing an extreme increase between 1990 and 1995. In 1995 there were 32,115 vehicles per day passing along the busiest road of Olomouc, the Velkomoravská Street (as compared to 15,553 vehicles per day in 1990). There is a general expectation of a continuing five-percent annual increase in the number of passing vehicles.

4. Ambient air pollution in the city of Olomouc in the period from 1991 – 2000

Sulphur dioxide (SO_2)

Interannual Variations (Fig. 2)

In 1991, SO_2 concentrations were monitored only at the stations of Flora (45 μg. m^{-3}) and Čapka Choda (48 μg. m^{-3}). There was a decrease in concentration levels recorded at the both stations between 1991 and 1992, then a slight increase occurred between 1992 and 1993, changing into a new decrease between 1993 and 1994, and reaching down to less than a half of the concentration values recorded in 1991.

In 1994, five new automatic stations started to monitor sulphur dioxide, while the Flora and Čapka Choda stations ended their operation in 1997. There was a steep decline of SO_2 concentration levels recorded at all of the stations, except for the City Hall station, where the mean annual concentration remained almost unchanged. Within the period 1991 – 2000, maximum values of mean annual concentrations were recorded at the Čapka Choda station (48 μg. m^{-3} in 1991) and at the Hodolany station (48 μg. m^{-3} in 1997 and 46 μg. m^{-3} in 1996). Concentration values in 2000 ranged between just a quarter and a third of the values recorded in 1997. The limit value of the mean annual SO_2 concentration (60 μg. m^{-3}) was not exceeded an any of the monitoring stations during the period 1991 – 2000.

Maximum average of the mean annual SO_2 concentrations in the period 1991 – 2000 was recorded at the Hodolany station (29.36 μg. m^{-3}), while the minimum average comes to the CHMI station (15.35 μg. m^{-3}).

Category of sources	SO_2	NO_x	Solid particles	CO	C_xH_y
REZZO 1	1,060.800	656.200	95.800	235.000	228.300
REZZO 2	144.591	130.216	131.290	243.089	98.420
REZZO 3	525.700	203.700	358.800	2,223.900	497.800
Total	1,731.091	990.116	585.890	2,701.989	824.520

Tab. 3: Total emissions (in tons per year) in the Olomouc City in 1999 by REZZO categories (according to Office of the District of Olomouc, 2000)

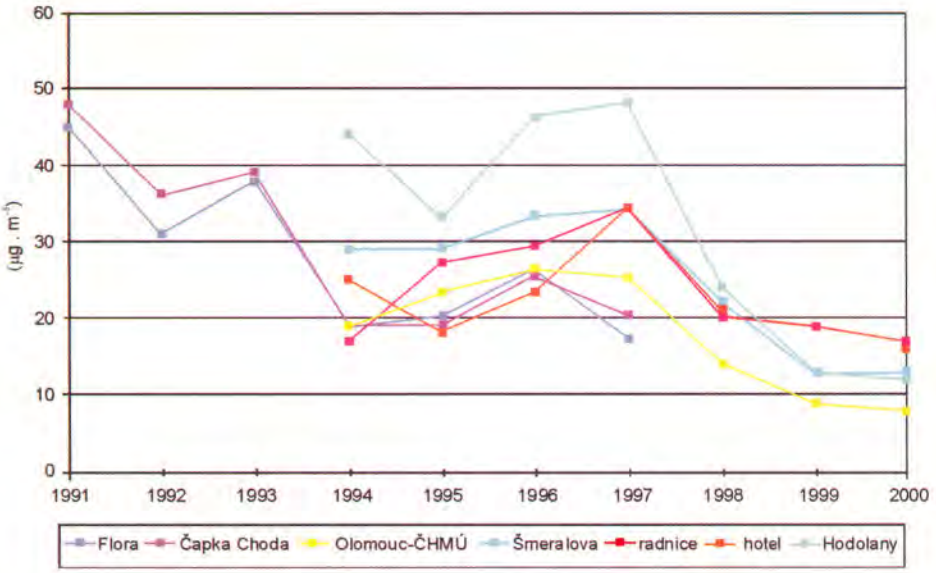

Fig. 2: Average annual SO_2 concentrations (in µg. m^{-3}) in the monitoring stations of Olomouc (1991 – 2000)

Cold and warm half a year characteristics

Higher values of the average monthly SO_2 concentrations occur in the cold half a year (October–March) as compared with the warm half a year (April–September). The least significant difference was recorded at the Hodolany station, while the most significant difference occurred at the Čapka Choda station. There is an obvious long-term decrease in average SO_2 concentrations in the winter season. The highest averages of the cold half a year were recorded at the Čapka Choda station (51.3 µg. m^{-3}) and at the Flora station (50.2 µg m^{-3}). The lowest average was measured at the CHMI station (24.8 µg. m^{-3}). Interannual course in the warm half a years was quite balanced at all stations within the studied period. There was just one exception – at the Hodolany station, which was showing maximum levels of average air pollution during the whole period 1991–2000 (37.7 µg. m^{-3}). The lowest average concentrations were recorded at the CHMI station (8.5 µg. m^{-3}).

Annual course

There is an obvious growth in air pollutant concentrations in the months of the cold half a year and a parallel decline in the warm half a year. The annual course was similar or nearly the same at all of the stations, the closest shape being recorded at the Flora and Čapka Choda stations. At the mentioned two stations the steepest increase was also recorded in the cold half a year (October–March) and the most significant decrease in the period from February–April. From April to October the highest concentrations were recorded at the Hodolany station.

Extreme values

The maximum averaged 24-hour concentration of SO_2 was recorded in December 1991 at the Čapka Choda station (512 µg. m^{-3}), while the minimum of 1 µg. m^{-3} was reached down at various stations in a wide range of months during the period under study.

Spatial distribution of SO_2 concentrations (Fig. 3 – see cover p. 2)

Spatial distribution of mean annual SO_2 concentrations was studied in a more detailed look for the years 1994, 1997 and 2000.

In the year 1994, the eastern part of the city was the most seriously affected area. Mean annual SO_2concentrations were 32.0–44.1 µg. m^{-3}. Medium mean annual SO_2 concentrations were recorded in the southern and south-eastern part of the city (20–32 µg. m^{-3}). The least polluted parts of the city were the historical core and the north-west (17–20 µg. m^{-3}).

In 1997, the eastern part of the city (areas eastwards of the Morava River) was the most polluted again. Mean annual SO_2 concentrations ranged between 36–48 µg. m^{-3}, with the intensity of pollution increasing from the east to the west. In the northern and southern parts together with the historical core, the concentrations of SO_2 reached 28–36 µg. m^{-3}. The least affected parts of the city were the west and the north-west (concentrations ranging between 20–28 µg. m^{-3}).

In 2000, mean annual SO_2 concentrations ranged between 8.0–17.3 µg. m^{-3}. Concentrations between

14.0–17.3 μg. m^{-3} were recorded in the historical core and in the south-west. The western part of the city showed the concentrations of 12.0–14.0 μg. m^{-3}. In other parts of the city, the concentrations were as low as 7.0–12.0 μg. m^{-3}.

Nitrogen oxides (NO_x)

Interannual variations (Fig. 4)

An almost balanced interannual course occurred at the Flora and Čapka Choda stations (monitoring between 1991–1997). Stagnation at the Flora station, increase at Hotelový dům and CHMI and decrease at the other four stations were recorded in years 1994 and 1995. In 1995 – 1996, the NO_x concentrations declined at the CHMI, Hotelový dům, Flora and Čapka Choda stations, but increased at the City Hall, Hodolany and Šmeralova stations. The period of 1996 – 1997 showed a slight increase or stagnation at the Flora, Čapka Choda and Šmeralova stations, but a steep growth at the other ones. In the years 1997 and 1998, the concentrations increased at the Šmeralova and Hotelový dům stations, while decreasing at the other ones. A steep decrease occurred at the Hodolany station between 1998–1999, but the concentrations showed a general decrease at all monitoring stations. A new increase started between 1999 and 2000, except for the Hotelový dům station.

The highest mean annual NO_x concentration in 1991 – 2000 was recorded at the Hotelový dům station (64.17 μg. m^{-3}), and the lowest one was recorded at the Čapka Choda station (23.7 μg. m^{-3}).

As compared with the long-term period of measurements, the interannual course between the years 1991 – 1994 was quite balanced. There was a decrease between 1994 and 1996, followed by a new steep increase until 1997, then a decrease again (reaching down to the situation of 1995, except for the Hotelový dům station), turning into a slight increase between 1999 and 2000. The limit for annual NO_x concentration (80 μg. m^{-3}) was exceeded only once – at the Hotelový dům station in 1998 (87 μg. m^{-3}). The highest mean annual concentrations were recorded at this station during the whole studied period and resulted most likely from the proximity of the station to the main traffic lines stretching through the city of Olomouc.

Cold and warm half a year characteristics

Similarly as the SO_2 concentrations, their levels were higher at the cold half a year. The least significant difference occurred at the Čapka Choda station, the most significant one at the Šmeralova station. The interannual course appears similar at all stations. The highest average concentrations in the cold half a year (82.2 μg. m^{-3}) were recorded at the Hotelový dům station during the whole period, while the lowest average concentrations were measured at the Čapka Choda station (29.1 μg. m^{-3}). In the warm half a years of 1991 – 2000 there was a balanced course at the Flora, Čapka Choda, CHMI and Šmeralova stations. A wider range of concentrations was recorded at other stations. A steep growth occurred between 1995 and 1997 at the Hodolany station and between 1996 and 1998 at the Hotelový dům station. The most significant decrease was observed at the Hodolany station in the period of 1997 – 1998 and at the Hotelový dům station in the period from 1998 – 1999. The highest average concentrations during the warm half a years of 1991 – 2000 were recorded at the Hotelový dům station (56.8 μg. m^{-3}), except for just one value higher at the Hodolany station (in 1996). The

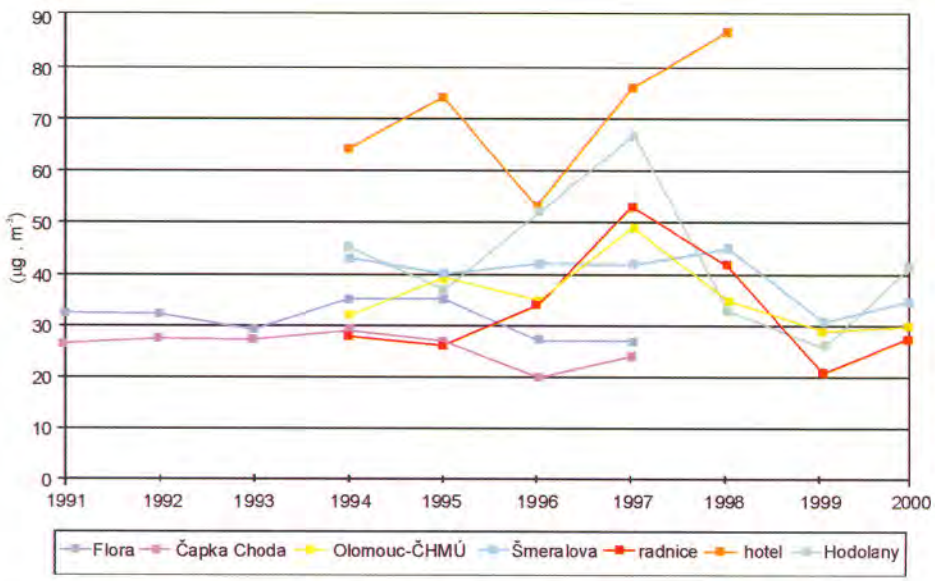

Fig. 4: Mean annual NO_x concentrations (in μg. m^{-3}) at the monitoring stations in Olomouc (1991 – 2000)

lowest average concentrations were recorded at the Čapka Choda and CHMI stations (20.8 μg. m^{-3}).

Annual course

The average monthly NO_x concentrations were increasing regularly in the cold half a years, but this feature is not as significant as in the case of SO_2. There is an exception at the Hotelový dům station, where the steepest growth was bound to January – February and August – November. The highest NO_x concentrations were recorded at the Hotelový dům station during the period 1991 – 2000 all year round.

Extreme values

The maximum average diurnal NO_x concentration of 368 μg. m^{-3} was reached in January 1993 at the Flora station, and the minimum average diurnal concentration of 1 μg. m^{-3} was recorded in May 1995 at the Hodolany station.

Spatial distribution of NO_x concentrations (Fig.5 – see cover p. 2)

Spatial distribution of mean annual NO_x concentrations was measured for the years 1994, 1997 and 2000.

In 1994, the highest mean annual NO_x concentrations in the south-western part of the city were bound to the proximity of main road crossings. There was a belt of concentrations between 36 – 50 μg. m^{-3} neighbouring to the most affected area, and the eastern part of the city reached 36 – 46 μg. m^{-3}. The mean annual concentrations were showing an increase in the direction from the east to the west, the lowest values having been recorded in the historical core and in the north-western part of Olomouc.

In 1997, the most affected area was that around the Hotelový dům station (55 – 76 μg. m^{-3}). Another severely polluted part of the city was the area east of the Morava River (55 – 67 μg. m^{-3}). Least polluted were the eastern and north-western parts of the city (23 – 40 μg. m^{-3}) and the areas located to the south and south-west of the town centre (27 – 40 μg. m^{-3}). In the remaining parts of the city, the concentrations amounted to 40 – 55 μg. m^{-3}.

The situation in 2000 was similar to the situations of 1994 and 1997. The most polluted area was the south-western part of the city (50 – 59 μg. m^{-3}). Medium NO_x pollution was bound to a belt bordering with the area mentioned above (44 – 50 μg. m^{-3}) and the eastern half of the city (37 – 44 μg. m^{-3}). Least polluted were the historical core, and the north or north-west (27.5 – 37 μg. m^{-3}).

Suspended particulate matter (SPM)

Interannual variations (Fig 6)

In the period 1991 – 1994, SPM was monitored only at the Flora and Čapka Choda stations. Two other stations were added in 1994: the CHMI and the Šmeralova station. It is possible to read a similar trend of interannual variations – a stagnation and a slight decrease, except for the period between 1995 and 1996. A steep decline occurred at the CHMI station, while there was a certain increase at the Flora, Čapka Choda and Šmeralova stations.

The highest mean annual SPM concentration for the period 1991 – 2000 was recorded at the Flora station (53.92 μg. m^{-3}), and the lowest one at the Šmeralova station (36.27 μg. m^{-3}).

Month	518	519	1075	1197
I	74.8	59	51.8	52.3
II	83.5	66.3	59.8	53.7
III	75.5	56.7	47	43.8
IV	66.5	40.3	41	33.6
V	48.4	33.8	39.4	29.6
VI	45.0	33.2	31.3	29
VII	45.0	33.3	35.2	31.5
VIII	45.4	35.3	34	35.2
IX	43.4	33.8	30.1	36
X	59.2	45.5	36	41.6
XI	54.3	41.3	46.1	43.2
XII	60.0	43	47.3	42
year	53.92	40.12	38.38	36.27
X – III	67.9	52.0	48.0	46.1
IV – IX	49.0	35.0	35.2	33.8

Tab. 4: Mean monthly SPM concentrations (μg. m^{-3}) in Olomouc (1991 – 2000)

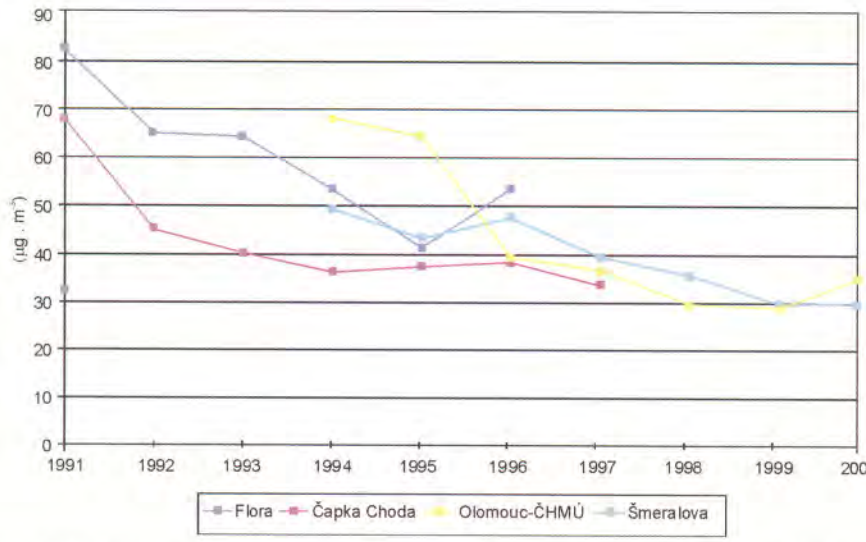

Fig. 6: Mean annual SPM concentrations (μg. m^{-3}) measured at the monitoring stations in Olomouc (1991 – 2000)

The annual concentration limit (60 μg. m^{-3}) was exceeded six times during the period 1991 – 2000. In 1991, such an extreme occurred at the Flora (83 μg. m^{-3}) and Čapka Choda stations (68 μg. m^{-3}), in 1992 at the Flora station again (65 μg. m^{-3}), in 1993 also at the Flora station, while in 1994 – 1995 the limit value was exceeded at the CHMI station (68 μg. m^{-3} in 1994 μg. m^{-3} and 64 μg. m^{-3} in 1995).

Cold and warm half a year characteristics

The SPM concentrations were higher in the cold half a year, but the range of extreme concentrations is almost the same at all stations. Interannual variations of the average SPM concentrations were similar at all stations as well. Only at the Flora station, the increase in 1996 – 1997 was going against the decrease recorded at all other stations. The highest average concentrations in the cold half a year were reached at the Flora station (68.1 μg. m^{-3}), the lowest at Šmeralova station (46.5 μg. m^{-3}). The variations of average SPM concentrations in the warm half a years 1991 – 2000 are similar to the variations in 1991 – 1994 and 1996 – 2000 (except for the Flora station in the years 1996 – 1997). A steep decline in the concentrations recorded at the Flora station in 1994 – 1995 turned into a steep growth between 1995–1996. A significant decrease occurred at the CHMI station in 1995–1996. The highest average monthly SPM concentrations in the warm half a year were reached in a long-term period at the Flora station (50 μg. m^{-3}), the lowest ones at the Šmeralova station (32.3 μg. m^{-3}).

Annual course

The annual course appears very similar for all stations. The highest concentrations were reached in February, then there was a decrease starting in May, followed by a stagnation until October, which turned into a new increase again. The highest values throughout the year were recorded at the Flora station in the period 1991 – 2000.

Extreme values

The maximum diurnal SPM concentration was reached at the Flora station in January 1991 (390 μg. m^{-3}). On the other hand, SPM concentrations were very close to zero in some months.

Spatial distribution

Spatial distribution of mean annual SPM concentrations was assessed for the years 1994 and 1997.

In 1994 isolines marking the constant SPM concentration levels were running approximately in the east-west direction, turning to the north-east and to the north at the eastern margin. The most affected areas were the south-western, southern, south-eastern and eastern parts of the city (56 – 64 μg. m^{-3}). The concentrations were decreasing to the north (42 – 56 μg. m^{-3}), reaching the lowest values of 42 – 34 μg. m^{-3}.

In 1997, the most affected parts of the city were the east, the historical core and the area to the north of it. Mean annual concentrations ranged between 64 – 70 μg. m^{-3}. These areas were bordered by a belt of slightly lower concentrations (56 – 64 μg. m^{-3}). Least affected were the eastern areas next to the historical core and the southern areas (48 – 56 μg. m^{-3}). The lowest concentrations (36 – 56 μg. m^{-3}) were recorded in the western part of the city. In general, the concentrations were decreasing from the east to the west.

Ground-level ozone (O_3)

Ground-level ozone, unlike its stratospheric relative, rises in chemical reactions from precursors such as nitrogen oxides or volatile organic compounds, making use of the sunshine and oxygen.

Interannual variations (Fig.7)

The ground-level ozone concentrations were monitored in Olomouc during 1991 – 2000 at two stations only: Šmeralova station (in 1995 – 2000) and Hotelový dům station (in 1996 – 1998). Šmeralova station exhibited some growth in the values between 1995 and 1996, which was followed by a decrease in 1996 – 1997 and a new growth in 1997 – 2000. Hotelový dům station exhibited an increase in 1996 – 1997 and a slight decrease in 1997 – 1998. As compared with Station Hotelový dům, Šmeralova station recorded higher concentrations during the whole period 1991 – 2000.

The higher O_3 concentration in 1995 – 2000 was bound to the Šmeralova station (47.15 μg. m^{-3}), while the concentrations were lower at the Hotelový dům (35.18 μg. m^{-3}).

Cold and warm half a year characteristics

The concentrations were higher in the winter half a year. In the average O_3 concentrations for the winter half a years of the period from 1995 – 2000 there are two clear points of the maximum (in 1996 and 1999), bridged by a balanced period of 1997 – 1998. At the Hotelový dům station, there was an increase in the period 1996 – 1997, followed by a stagnation between 1997 and 1998. Average monthly concentrations for the winter half a years of 1995 – 2000 were ranging between 25 – 40 μg. m^{-3} (Šmeralova station 32.2 μg. m^{-3}, Hotelový dům station 34.8 μg. m^{-3}). Average monthly concentrations for the summer half a years of 1995 – 2000 follow a balanced trend at the Šmeralova station during the whole studied period. At the Hotelový dům station, the increase in1996 – 1997 changed into a stagnation in 1997 – 1998. At the Šmeralova station, the average monthly concentration for the summer half a year was 70 μg. m^{-3}, at the Hotelový dům it amounted to 41.2 μg. m^{-3}.

Annual course

The period of monitoring the ground-level ozone concentrations in Olomouc is not long enough to obtain a representative analysis of the annual course of average monthly O_3 concentrations. At Šmeralova station, there was a typical increase in the concentrations between January and April, maximum levels having been reached in April and May and the high level of concentration continued between May and August. A steep decline started in August.

Extreme values

The maximum average diurnal O_3 concentration reached 153 μg. m^{-3} in April 1996 at the Šmeralova station, and the minimum average diurnal O_3 concentration of 3 μg. m^{-3} occurred several times at both the Šmeralova and the Hotelový dům stations.

Spatial distribution of ground-level ozone concentrations

There is no possibility to draw maps that would represent the situation in the O_3 concentrations during 1995 – 2000, the reason being lack of data available. It may

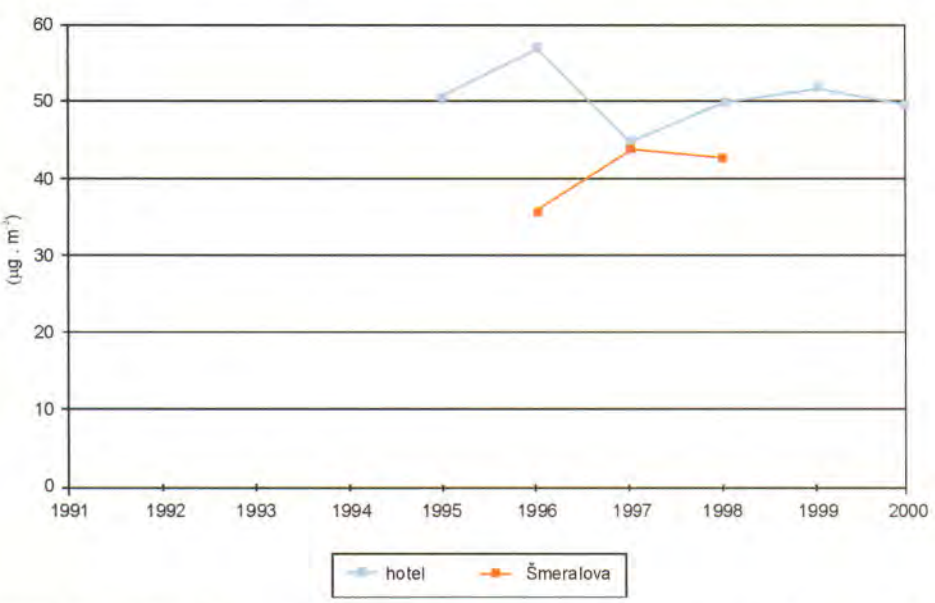

Fig. 7: Mean annual ground-level ozone concentrations (in μg. m^{-3}) at the monitoring stations in Olomouc (1995 – 2000)

be expected that the ground-level ozone concentrations were increasing from the north-western parts to the south-eastern parts of the city.

5. Air quality index

Air quality index (IKO) is a standard tool to assess the complex influence of pollutants in the ambient air onto the population's health. Methodology of calculating the index was among other things described by B. Kotlík (1997). The index helps in the assessment of air quality based on pollutant concentration measurements. It has both a numerical and a verbal expression to quantify the amounts at which the studied pollutants can affect the population:

IKO_r 0 to 1 = clean, healthy ambient air,
IKO_r 1 to 2 = health-suitable ambient air,
IKO_r 2 to 3 = slightly polluted, health-acceptable ambient air,
IKO_r 3 to 4 = polluted ambient air, sensitive persons endangered.

The air quality index is calculated from annual, diurnal or short-term concentrations of the monitored pollutants. All pollutants with a stated concentration limit value can be incorporated into the IKO assessment.

$$IKO_r (SO_2 + NO_x)$$

The $IKO_r (SO_2 + NO_x)$ values developed in a similar way at all stations during the period 1991 – 2000. There was a slow decrease in 1991 – 1994, followed by a balanced course in 1994 – 1996. A new increase occurred in 1996, reaching to a maximum in 1997 and decreasing again, turning into another increase in 1999 – 2000. The maximum levels of $IKO_r (SO_2 + NO_x)$ were reached at Hotelový dům and Hodolany during the studied period.

Spatial distribution (Fig. 8)

In 1994, the IKO_r field values ranged between 0.95 – 1.95 (health-suitable ambient air). The values were increasing in the direction from the north-west to the south-east or east. The maximum values were recorded around Hodolany (1.95) and Hotelový dům (1.82), the lowest values were bound to the south-western part of the city.

In 1997 the $IKO_r (SO_2 + NO_x)$ ranged between 0.95 and 2.45. The values were increasing from the north-west to the south-east. Areas around Hotelový dům (index values 2.0 – 2.3) and around Hodolany in the eastern part of the city (index values 2.0 – 2.45) were classified into the category of *slightly polluted, health-acceptable ambient air*. Most of the city showed values ranging between 1.0 and 2.0 which means *health-suitable ambient air*. The lowest values of IKO_r, not exceeding

Station	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Flora	1.73	1.38	1.50	1.13	1.16	1.7	0.93	-	-	-
Čapka Choda	1.69	1.25	1.48	1.01	0.97	0.97	0.95	-	-	-
CHMI	-	-	-	1.07	1.38	1.08	1.54	1.01	0.77	0.76
Šmeralova	-	-	-	1.52	1.40	1.64	1.61	1.38	0.91	0.98
City Hall	-	-	-	0.95	1.14	1.36	1.83	1.28	0.84	0.95
Hotelový dům	-	-	-	1.82	1.84	1.57	2.30	2.15	-	1.51
Hodolany	-	-	-	1.95	1.48	2.14	2.45	1.20	0.82	1.08

Tab. 5: Annual air quality index – $IKO_r (SO_2 + NO_x)$ at the stations in Olomouc in 1991 – 2000 (according to the Historical analysis of SO_2, NO_x and SPM data measured in the city of Olomouc (1999) and S. Kadlčík (2002)

Station	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Flora	3.17	2.69	2.83	2.12	1.85	2.23	2.15	-	-	-
Čapka Choda	3.05	2.13	2.22	1.64	1.64	1.74	1.57	-	-	-
CHMI	-	-	-	2.47	2.61	1.73	1.98	1.40	1.21	1.05
Šmeralova	-	-	-	2.33	2.09	2.42	2.20	1.82	1.34	1.38
City Hall	-	-	-	2.35	-	-	2.47	1.45	-	-
Hotelový dům	-	-	-	2.62	-	-	3.06	2.43	-	-
Hodolany	-	-	-	3.10	-	-	3.08	1.98	-	-

Tab. 6: Annual air quality index – $IKO_r (SO_2 + NO_x + SPM)$ at the stations in Olomouc in 1991 – 2000 (according to the Historical analysis of SO_2, NO_x and SPM data measured in the city of Olomouc (1999) and S. Kadlčík (2002)

1.0 (*clean, healthy ambient air*), were recorded around the stations of Flora (0.93) and Čapka Choda (0.95) in 1997.

In the year 2000, the IKO_r values were lower as compared with the values of 1994 and 1997 all around the city. They were ranging between 0.76 to 1.51 (categories *clean, healthy ambient air* and *health-suitable ambient air*). The highest values were reached at the stations Hotelový dům (1.51) and Hodolany (1.08).

IKO_r (SO_2 + NO_x + SPM)

Values of IKO_r (SO_2 + NO_x + SPM) were decreasing gradually in the whole period from 1991 – 2000. The most significant decrease occurred between 1997 – 1998. Concerning the average values of IKOr, the order of the stations is as follows: Hodolany (2.72), Hotelový dům (2.70), Flora (2.43), City Hall (2.09), Čapka Choda (2.00), Šmeralova (1.94) and CHMI (1.78).

The IKO_r values ranged between 1.57 and 3.08 in 1997, increasing in the direction from the north-west to the south-east. The highest levels, corresponding to the category of *polluted ambient air, sensitive persons* endangered (index values between 3 and 4), were recorded around the stations of Hodolany (3.08) and Hotelový dům (3.06). In most parts of the city, the index values were ranging between 2 and 3 (*slightly polluted, health-acceptable ambient air*). Only the value recorded for the Čapka Choda station and its surroundings (1.54) was classified as *health-suitable ambient air*.

6. Conclusion

Spatial distribution and air pollution values in the city of Olomouc are determined by the location and structure of air pollution sources and also by the character of the prevailing dispersion conditions. The largest sources of air pollution in the Olomouc area included traffic (road traffic in particular), Heating

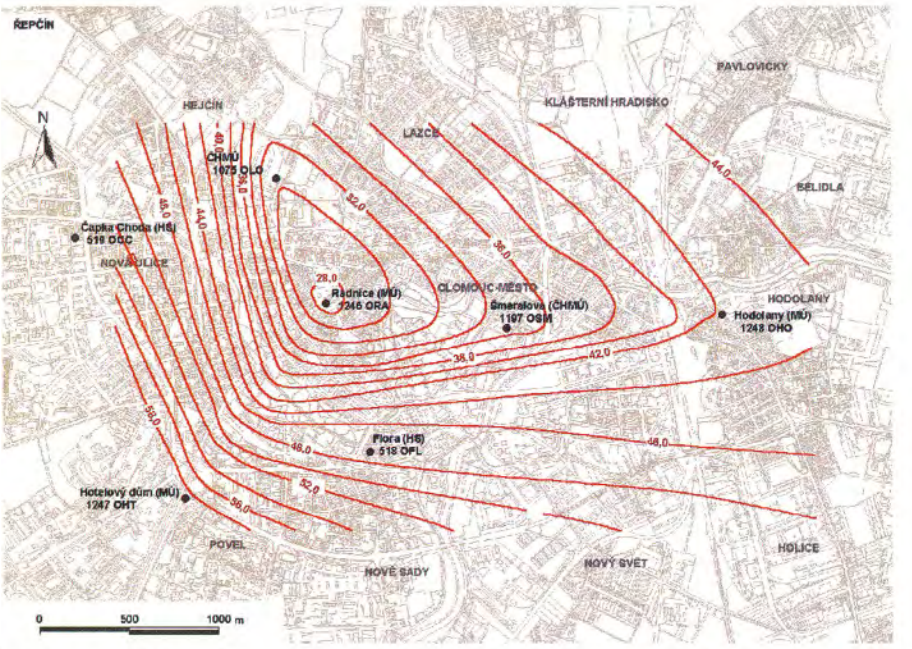

Fig. 8: Spatial distribution of IKOr (air quality index- annual) in Olomouc 1991-2000

Spatial distribution

Index values ranged between 1.64 and 3.1 in 1994, increasing in the direction from the west to the east. The maximum value (3.10) was recorded around Hodolany (*polluted ambient air, sensitive persons endangered*), followed by the value around Hotelový dům (2.62). In most parts of the city, the IKO_r values ranged between 2 and 3 which is *slightly polluted, health-acceptable ambient air*. Areas around the Čapka Choda station were characterised by values ranging between 1 and 2 which is *health-suitable ambient air*.

Plant Olomouc, Peak Heating Plant Olomouc, local heating and construction works. According to the meteorological characteristics, the most significant feature is the prevailing north-western wind, resulting in a gradual increase of air pollutant concentrations in the direction from the north-west to the south-east. Also the more often occurring inversions during the cold half a year result in higher air pollutant concentrations and possibly exceeded air pollution limits. Both the prevailing wind direction and the occurrence of inversions are partly given by the terrain features in Olomouc and its surroundings.

The most severe impact on the ambient air in the city comes from the emissions of NO_x, both the half an hour concentration limits and the average diurnal concentration limits being exceeded. The largest source of the emissions is traffic (contributing up to 70 % of the whole amount). A certain improvement can be expected after a new road bypass is completed. Air pollution limits for SO_2 and suspended particulate matter (secondary suspension prevailing) were exceeded only under extremely unfavourable dispersion conditions. A current issue is pollution by ground-level ozone; the monitoring of its concentrations needs to be further extended. In a long-term comparison, stagnation or decrease occur in air pollution with SO_2 and SPM, but no significant trend can be recognised for NO_x and ground-level ozone.

Air quality index IKO_r (SO_2 + NO_x + SPM) indicates a relatively good air quality in the city of Olomouc during the period 1991 – 2000. The index values were reaching up to 2 or 3 during the studied period, which means a *slightly polluted, health-acceptable ambient* air. The most frequent IKO_r values ranged between 1 and 2, which is *health-suitable ambient air*. The maximum IKO_r values were reaching up to the interval of 3 to 4 (*polluted ambient air, sensitive persons endangered*), but this was only episodic. The most seriously affected parts of the city were areas in the east and south-east (Hodolany and the areas close to the crossing of Velkomoravská and Brněnská streets, by the Hotelový dům).

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Authors´ addresses:

doc. RNDr. Miroslav VYSOUDIL,CSc.
Palacký University
Faculty of Science, Dpt. of Geography
Svobody 26, 771 46 Olomouc, Czech Republic
e-mail: vysoudil@prfnw.upol.cz

Mgr. Martin JUREK
Palacký University
Faculty of Science, Dpt. of Geography
Svobody 26, 771 46 Olomouc, Czech Republic
e-mail: jurekm@pfnw.upol.cz

Reviewer:

RNDr. Evžen QUITT, CSc.

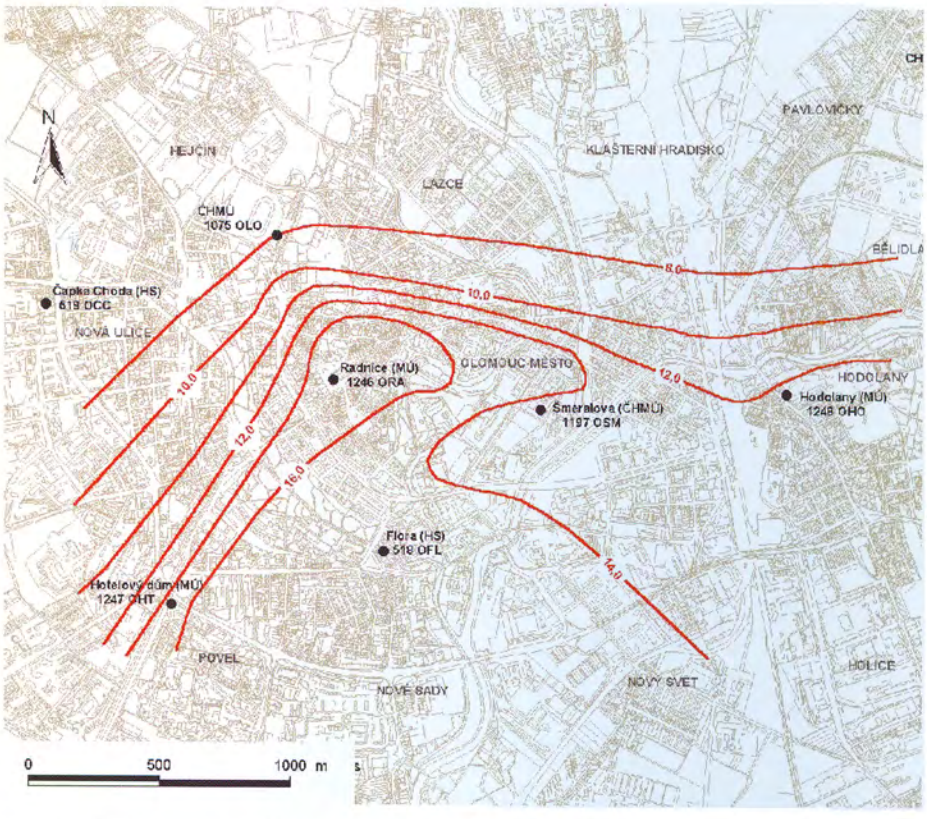

Fig. 3: Spatial distribution of SO_2 in Olomouc 1991 – 2000

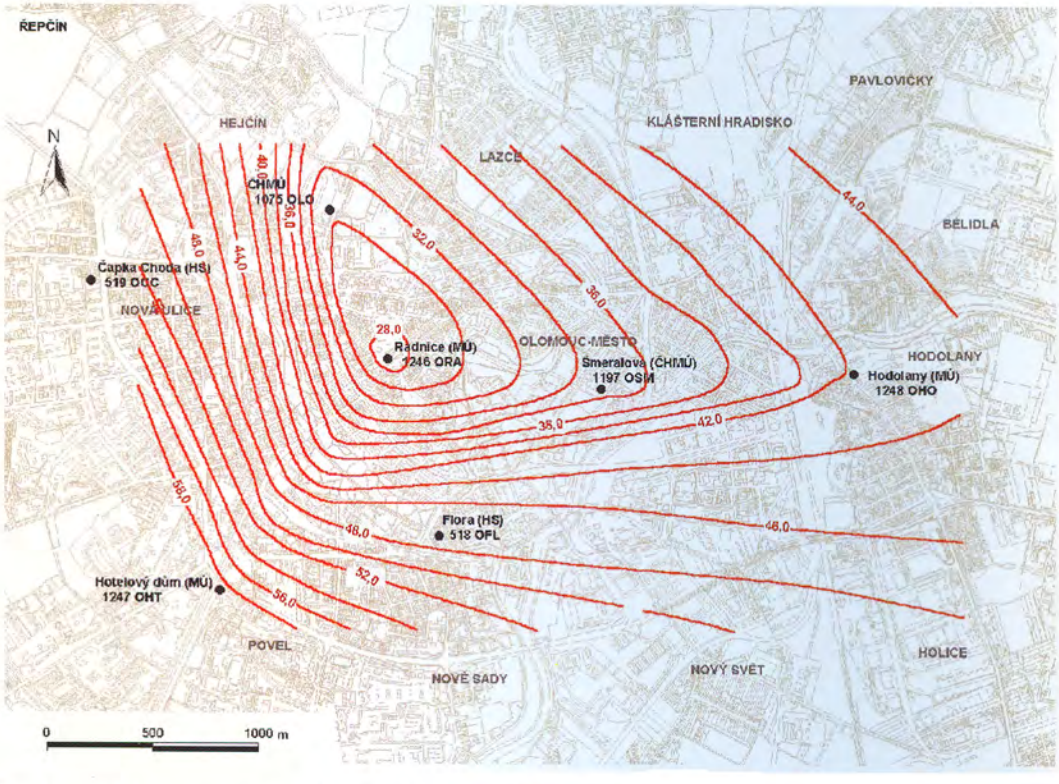

Fig. 5: Spatial distribution of NO_x in Olomouc 1991 – 2000.

Illustrations to the paper of M. Vysoudil, M. Jurek