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COVID-19 lockdown and particle exposure of road users

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ABSTRACT

Introduction: In 2020, due to the outbreak of COVID-19, there has been an unprecedented decrease in road traffic in almost all urbanized areas around the globe. This has undoubtedly affected the ambient air quality.

Methods: In this study mobile and fixed-site measurements of aerosol particle concentrations in the ambient air in one of the busiest streets in Lublin, a mid-sized city in Central Europe (Poland) during the COVID-19 lockdown in the spring of 2020 were performed. Based on the measurements particle doses received by road users during different times of the day were assessed. The obtained results were compared with corresponding pre-COVID-19 measurements also performed in the spring which were available only from 2017.

Results: During lockdown the mass concentration of traffic-related submicrometer PM$_{1}$ particles and number concentration of ultrafine PN$_{0.1}$ particles was significantly reduced. This resulted in a decrease of doses inhaled by road users as well as of particle doses deposited in their respiratory tracks. The greatest reductions of respectively over 2 times and over 5 times were observed during the day for total particles and traffic-related particles. Smaller reductions indicating the existence of relatively intensive non-traffic emissions were reported at night.

Conclusions: Substantial decrease in traffic intensity in the city caused by lockdown restrictions resulted in a significant reduction in the concentration of vehicle-generated particles in the ambient air. This in turn could have resulted in smaller doses inhaled by the inhabitants, specifically road users, which should have a positive impact on their health.

1. Introduction

The implementation of lockdown measures by governments of numerous countries in order to slow down the outbreak of COVID-19 resulted in a notable improvement in the air quality in many urban areas worldwide (Hudda et al., 2020; Nigam et al., 2021). Such improvement can be mainly attributed to an unprecedented drastic reduction in car traffic, as well as – to a lesser degree – decreased emission of air pollutants from the industrial sector slowed down by the lockdown. The studies of Wang et al. (2020a) conducted in over 300 cities in China indicated a huge decrease of PM$_{2.5}$, PM$_{10}$, CO, SO$_2$, and NO$_2$ levels in the ambient air as well as a considerable improvement of the Air Quality Index. However, certain studies e.g. conducted in Europe and China indicated that not all air pollutants were reduced at that time (Sicard et al., 2020; Huang et al., 2020). Increased aerosol particle and O$_3$ concentrations have been reported which were attributed to complex interactions between the emitted pollutants that were not connected with the implemented COVID-19 lockdown restrictions. Unfavorable meteorological conditions could also have been an essential contributing factor (Le et al., 2020).

Some studies suggest that certain air pollutants could promote the transmission of pathogens and increased occurrence of diseases.
caused by them (Cui et al., 2003; Khreis et al., 2017). In the case of the SARS-CoV-2 coronavirus, chronic exposure to ambient air pollutants might be conducive to the spread of the COVID-19 pandemic. High concentrations of such pollutants may be connected with a higher risk factor of severe COVID-19 outcomes as well as a higher number of COVID-19-related deaths (Domingo et al., 2020; Travaglio et al., 2020).

Road traffic and other anthropogenic emission sources are considered as main air pollution contributors in cities. They may cause serious pollution problems related to e.g. significant deterioration of urban air quality or smog (Font and Fuller, 2016; Sinha and Kumar, 2019) which mainly result from the emissions of such pollutants as particulate matter, nitrogen oxides, carbon monoxide, hydrocarbons and ozone. Their elevated concentration levels adversely affect the health of city residents and they significantly contribute, among other things, to increased risk of respiratory and cardiovascular diseases and may lead to premature deaths. For example in European Union (EU) countries in 2016 the number of premature deaths attributed to excessive exposure to fine particulate matter (PM$_{2.5}$), nitrogen dioxide and ozone was 374,000, 68,000 and 14,000, respectively (EEA, 2019). The World Health Organization (WHO, 2016), while assessing the impact of PM$_{2.5}$ in the ambient air on global health, estimated that 3 million deaths annually are attributable to this pollutant. While considering urban air quality and the related health hazard it needs to be clearly stated that these are valid issues irrespectively of the size of the city. Usually air pollutant concentrations are higher in larger cities and more densely populated areas. For example, in China the population density is one of the dominant factors affecting PM$_{2.5}$ concentrations in the ambient air (Wang et al., 2021a). However, there are cases in which the air quality in relatively small cities and towns as well as industrial districts is worse than in large agglomerations (Xie et al., 2019; Agrawal et al., 2021).

Recently, while considering health impacts of particular matter in cities, greater attention is drawn to road traffic-emitted submicrometer and specifically to ultrafine particles (UFPs) with an aerodynamic diameter of less than 0.1 μm. They are considered as ones having more aggressive health implications, greater potential for lung deposition and translocation than regulated larger-sized particles (WHO, 2013). UFPs compared with their larger counterparts have a negligible mass and thus their number concentrations are preferentially measured and evaluated (Kumar et al., 2014).

Thus far, studies on the impact of COVID-19 lockdown measures on the urban air quality were mainly carried out in megacities (Connerton et al., 2020; Islam and Chowdhury, 2021). Such research was not or only rarely performed in small or mid-sized cities. The majority of the conducted studies were aimed at comparing the measured concentrations of air pollutants before and during the pandemic, as well as at indicating an improvement in the air quality. Although the obtained results did not always confirm a logical trend in the reduction of the air pollution levels resulting from the economic lockdown, the mean exposure to air pollutants during the pandemic period decreased in the majority of the affected cities. Considering the above from the epidemiological point of view, the degree of reduction in the doses of pollutants received by city residents is relevant. Despite numerous studies carried out to date, the
positive impact of COVID-19 lockdown measures on roadside environments, including on the amount of traffic-related pollutants received by road users still remains unclear.

This work presents the changes of submicrometer particle mass and ultrafine particle number concentrations in the air along a busy road in Lublin, a mid-sized city in Central Europe during the COVID-19 lockdown introduced in the spring of 2020, compared with a corresponding period in 2017. The estimated doses of total and traffic-related particles inhaled by road users and deposited in their respiratory tract have also been presented.

2. Materials and methods

Research concerning changes in the particle exposure of road users in the spring of 2017 and during the COVID-19 lockdown introduced in the spring of 2020 was conducted in Lublin, eastern Poland. It is a relatively old (700 years), mid-sized city in Central and Eastern Europe with about 340,000 inhabitants and an area of approximately 147 km² (CSOP, 2017). Lublin is not considered as an industrial city and the adjacent areas are mainly rural (Geoportal.gov.pl). It has been selected for the case study as it is one of the most congested cities in Europe (TomTom Traffic Index, 2017). It has a relatively poor road infrastructure and a high number of old vehicles (older than 15 years) powered by gasoline and diesel engines – many of which exceed current emission standards. Therefore, traffic-related emissions are a major factor affecting the air quality in the city. Emissions from residential coal burning for heating purposes are another significant air pollution source, especially in the heating season (Polednik, 2013). The poor air quality in Lublin and in Poland generally which is one of the most polluted countries in the EU results from heavy reliance on coal. At present, coal is the dominant fuel in the Polish power industry accounting for about 80 percent of energy production (https://blogs.worldbank.org).

During the complete lockdown which lasted for over a month in Lublin in the spring of 2020 serious changes and restrictions to everyday life have been introduced. Among other things, mass events were canceled, restaurants, offices, schools and universities were closed and residents were encouraged to stay at home. Traffic was also drastically reduced. The congestion level during the lockdown decreased by more than 50% as well as the number of municipal transportation passengers. According to the Public Transport Authority in Lublin (ZTM, 2020) it was reduced by almost 90%. The introduced lockdown measures also resulted in changes in the fleet structure. The share of passenger cars decreased by approximately 10% (to ~61%). At the same time the share of trucks with diesel engines increased by almost 10% (to ~24%).

Aerosol particle concentrations in the ambient air were assessed during mobile and fixed-site measurements on one of the busiest streets in the city, along a 2.1 km route (Fig. 1) with three 4-way and three 3-way intersections (Polednik, 2021). According to data provided by the Road and Bridge Authority (RBA, 2018) the traffic volume at each of the intersections during the rush hour in normal conditions is up to 3000 vehicles per hour. The traffic on the monitored street demonstrates a typical bimodal pattern with a maximum intensity in the mornings (7:00–9:00) and afternoons (15:00–17:00). Increased traffic is also often observed in the evening (at around 20:00). This may be related to various activity undertaken by the residents after business hours such as shopping, leisure activities as well as attending sports events in the nearby sport facilities. When considering the intensity of the traffic on the monitored street in the given time, one has to bear in mind that it may be affected by many factors, including random incidents. Apart from the time of the day and the day of the week, the season and the related metrological conditions may be of significance. The changes in the traffic intensity may also result from road works or accidents on the considered or neighboring streets.

Mobile Air Pollution Analytic Laboratory (MAPAL) which consisted of a Renault Kangoo with installed measurement instruments was used to collect the measurement data. The route with the location of the sampling points for fixed-site measurements along with the details concerning the instruments and measurement procedures are presented elsewhere in Piotrowicz and Polednik (2019).

MAPAL was, among other things, equipped with particle mass (PM) and particle number (PN) concentration measurement instruments. Grimm Aerosol Spectrometer 1.109 with Nano Sizer 1.321 (Grimm Aerosol, Germany) was used for real time measurements of number concentrations of particles with sizes from 10 nm to 32 μm and mass concentrations of PM1, PM2.5 and PM10. Mass concentrations of the same particle fractions were also determined by DustTrak DRX monitor model 8533 (TSI Inc., USA). Number concentrations of particles with sizes ranging from 0.02 to 1 μm (PN0.1) were measured by P-Trak model 8525 (TSI Inc., USA). OPS 3330 (TSI Inc., USA) was used for measuring number concentrations of particle fractions greater than 0.3 μm.

Ambient air was supplied to the instruments through sampling tubes with inlets placed on the inside of the left side of the vehicle, at the height of approximately 1.7 m. The logging interval was set for all instruments to 6 s and the instruments were calibrated before the measurement series carried out in 2017 and 2020. Apart from particle concentrations, air temperature and relative humidity was also measured using a LB-520 thermo-hygrometer (LAB-EL, Poland). GPS (Garmin Nuvi 2460LMT) was also used for recording MAPAL’s position and speed. An HD camera (1080P Wide angle 170°) was used to monitor the traffic intensity.

The obtained concentration measurement results constitute an estimate of real values and depend on the type of instrument, its calibration and other affecting factors (Polednik et al., 2018).

The six measurements runs a day at 4-h intervals in both directions along the route were carried out. During each run, 5-min fixed-site measurements were performed at 11 stop points evenly distributed along the route during which MAPAL was parked on the sidewalk. The duration of each run was affected by the traffic intensity which depended on the time of the day and the day of the week. During measurements carried out in 2017, one full daytime run took about 103 min and one nighttime run took about 92 min. In 2020, due to a significantly lower traffic intensity, the duration of the runs was much shorter and during the daytime they took approximately 90 min, while at nighttime only approximately 70 min. While analyzing the results it was assumed that the traffic conditions during a single run were not subject to change.

Pre-lockdown data from mobile measurements in the spring season was available only from 2017. The use of measurement data obtained in other seasons for comparison would entail a risk of making mistakes and drawing inaccurate conclusions as such data could
be significantly impacted by various factors. Primarily, they could be affected e.g. by differing weather conditions which can have a major impact on aerosol particle concentrations in the ambient air. This material factor needs to be taken into consideration even while comparing data from measurements carried out in the same season and one should either apply multivariate models to eliminate or neutralize its impact (Xiang et al., 2020) or analyze only data from selected periods with the same or similar weather conditions (Chen et al., 2020). The latter approach has been adopted in this study. Results obtained during six consecutive runs carried out during a 24 h-period on 4–5 April 2017 (Tuesday–Wednesday) and 16–17 April 2020 (Thursday–Friday) are presented and analyzed. The temperature reported on those days was similar i.e. −17 °C during the day and −8.5 °C at night. The days slightly differed in terms of relative humidity whose day/night values amounted to 57/72% in 2017 and 38/54% in 2020, as well as in terms of wind speed which amounted to 13/13 km/h in 2017 and 28/10 km/h in 2020 (https://www.weatheronline.com).

While assessing the exposure to traffic-related particles, the contamination ratio (CR) values were computed from the following equation:

$$CR = \left( \frac{C - C_b}{C_b} \right) \times 100$$

(1)

where $C$ is the particle concentration in the ambient air obtained during mobile measurements and $C_b$ is the average background particle concentration at that time.

The dose of traffic-related particles ($ID$) inhaled by road users (drivers and pedestrians) was estimated with the use of a modified equation presented in Polednik and Piotrowicz (2020):

$$ID = V_T \times f \times \left( \frac{C - C_b}{C_b} \right) \times t$$

(2)

where $V_T$ is the tidal volume (assumed 800 cm$^3$ per breath), $f$ is the breathing rate (21 per minute) and $t$ is the time of exposure.

Deposited dose ($DD$) of particles (in the head airways, tracheobronchial and alveolar regions) was calculated from the formula:

$$DD = V_T \times f \times D \times C \times t$$

(3)

and deposited dose of traffic-related particles ($DD_T$) was obtained from the formula:

$$DD_T = V_T \times f \times D \times \left( \frac{C - C_b}{C_b} \right) \times t$$

(4)

where $D$ is the deposition fraction which is estimated based on the simplified equations fitted to the ICRP model (ICRP, 1994) and is the sum of the regional depositions (Hinds, 1999) determined by the median diameter ($d_p$) of particles and their inhalable fraction:

Fig. 2. Total and traffic-related particle mass concentrations PM$_1$ and particle number concentrations PN$_{0.1}$ during the day (D) and at night (N) in 2017 and 2020.
3. Results

Fig. 2 shows total and traffic-related mass concentrations of submicrometer particles PM$_1$ and total and traffic-related number concentrations of ultrafine particles PN$_{0.1}$ measured during the day and at night in 2017 and 2020.

It is clearly visible that during the lockdown period in 2020 lower concentrations of PM$_1$ and PN$_{0.1}$ were present in the ambient air, both during the day and at night.

Table 1 presents the average percentage contamination of ambient air by traffic-related particles as well as average doses of such particles inhaled by road users within an hour at the considered times of day in 2017 and in 2020. It demonstrates that irrespectively of the time of the day, the contamination ratio values and the inhaled doses were several times lower in 2020 as compared to 2017. The greatest contamination ratios determined for particle mass concentrations (PM) as well as the greatest inhaled doses were recorded in the evening (20:00) in both 2017 and 2020. It can be assumed that it is connected with the quantitative and qualitative changes of the emissions at that time, including with the greatest reduction of background particle mass concentrations. Usually the emissions from residential heating furnaces are less intensive at such time of the day, as cooking activities are less frequent and the furnaces are only used for maintaining the heat or are switched off and they are kept in such state until bedtime when they are activated once again.

Table 1

| Time     | Particles | CR (%)         | Dose (μg h$^{-1}$) | Dose (×10$^9$ pt h$^{-1}$) |
|----------|-----------|----------------|--------------------|-----------------------------|
|          |           | 2017           | 2020               |                             |
|          | PM$_1$    | 38(40) 28/209  | 76(6) 6/28         | 10.1(10.8) 7.6/56.4         |
|          | PM$_{2.5}$| 38(40) 28/210  | 76(6) 6/30         | 10.3(10.9) 7.7/57.5         |
|          | PM$_{10}$ | 34(37) 22/207  | 97(8) 8/29         | 11.6(12.7) 7.7/71.3         |
|          | PN$_{0.1}$| 125(135) 76/708| 33(49) 19/341     | 6.1(6.6) 3.7/34.5           |
|          | PN        | 120(123) 76/581| 31(41) 19/288     | 7.1(7.3) 4.5/34.3           |
|          | 12:00     | 54(213) 11/1633| 28(23) 26/138     | 9.7(38.5) 1.9/296           |
|          | PM$_1$    | 57(228) 11/1758| 27(22) 25/134     | 10.4(41.8) 2.0/322           |
|          | PM$_{2.5}$| 106(491) 13/3834| 32(28) 23/117    | 23.2(108) 2.9/843           |
|          | PM$_{10}$ | 163(257) 40/1353| 25(21) 19/83     | 4.8(6.7) 1.2/40.2           |
|          | PN$_{0.1}$| 146(226) 11/1767| 25(20) 19/85     | 5.3(8.2) 1.4/42.8           |
|          | PN        | 47(36) 43/230  | 12(12) 9/82       | 9.5(7.3) 8.7/46.5           |
|          | 16:00     | 49(36) 44/232  | 12(12) 10/80     | 9.8(7.4) 9.0/47.0           |
|          | PM$_1$    | 57(228) 11/1758| 27(22) 25/134     | 10.4(41.8) 2.0/322           |
|          | PM$_{2.5}$| 62(38) 57/240  | 13(11) 10/44     | 13.8(13.8) 1.2/51.4         |
|          | PM$_{10}$ | 173(215) 73/1176| 26(28) 17/150    | 8.5(7.2) 2.5/39.3           |
|          | PN$_{0.1}$| 166(203) 80/1056| 26(28) 17/143    | 6.6(8.0) 3.2/41.8           |
|          | PN        | 43(39) 42/220  | 12(12) 10/80     | 9.8(7.4) 9.0/47.0           |
|          | 20:00     | 70(53) 57/202  | 57(28) 51/207    | 20.2(15.5) 16.5/58.7         |
|          | PM$_1$    | 70(53) 57/200  | 56(29) 50/213    | 20.3(15.5) 16.6/58.8         |
|          | PM$_{2.5}$| 60(48) 45/174  | 45(39) 38/309    | 20.9(16.8) 15.6/60.6         |
|          | PM$_{10}$ | 38(50) 27/377  | 57(82) 30/412    | 3.1(4.0) 2.1/30.5           |
|          | PN$_{0.1}$| 38(47) 27/359  | 54(77) 29/423    | 3.7(4.3) 2.6/34.9           |
|          | PN        | 12(9) 12/58    | 7(4) 7/18        | 3.4(2.5) 3.4/16.6           |
|          | 0:00      | 14(11) 12/79   | 7(4) 6/19        | 4.2(3.6) 3.8/24.9           |
|          | PM$_1$    | 84(54) 67/278  | 31(32) 21/197    | 2.9(1.8) 2.3/9.5            |
|          | PM$_{2.5}$| 81(51) 64/250  | 29(29) 20/155    | 3.4(2.1) 2.7/10.5           |
|          | PM$_{10}$ | 10(10) 8/67    | 10(8) 9/45       | 3.5(3.5) 2.9/24.3           |
|          | PN$_{0.1}$| 10(10) 8/68    | 10(8) 9/47       | 3.6(3.7) 3.0/24.8           |
|          | PN        | 11(12) 8/74    | 12(11) 10/68     | 4.6(4.9) 3.1/29.6           |
|          | 4:00      | 34(80) 16/571  | 23(32) 16/207    | 1.8(4.2) 0.5/30.0           |
|          | PM$_1$    | 31(67) 10/466  | 20(27) 13/169    | 2.0(4.3) 0.7/30.0           |
|          | PM$_{2.5}$| 11(12) 8/74    | 12(11) 10/68     | 4.6(4.9) 3.1/29.6           |
|          | PM$_{10}$ | 34(80) 16/571  | 23(32) 16/207    | 1.8(4.2) 0.5/30.0           |
|          | PN        | 31(67) 10/466  | 20(27) 13/169    | 2.0(4.3) 0.7/30.0           |

Arithmetic average (standard deviation) median/maximum.
Measurement data concerning particle size distributions was used to estimate the particle doses deposited in the respiratory tract of road users. Fig. S1 presents mass-size distributions of total and traffic-related PM$_1$ particles and number-size distributions of total and traffic-related PN$_{0.1}$ particles representative for the considered daytime and nighttime measurement periods in 2017 and 2020. Table 2 presents median diameters, deposition fractions, average concentrations of total and traffic-related PM$_1$ and PN$_{0.1}$ particle fractions estimated for the considered daytime and nighttime measurement periods in 2017 and 2020. Average doses of such particles deposited in the respiratory system of road users during such periods have also been shown. It can be seen that generally the amount of the deposited particles was significantly lower during the COVID-19 lockdown in 2020 than in 2017, both during the day and at night. The greatest reductions of the deposited doses were observed during the day. The total mass of the PM$_1$ particles and the total number of PN$_{0.1}$ particles deposited during 1 h in the respiratory tract of road users were over two times lower (respectively 2.1 and 2.2 times). In turn, the mass and number of the deposited traffic-related particles were over 5 times lower i.e. 5.2 times lower for PM$_1$ particles and 5.3 times lower for PN$_{0.1}$ particles. At night the reductions of the deposited doses of the considered particle fractions were lower (ratio of about 2) while the lowest drops (ratio of about 1.3) were observed for total and traffic related mass of PM$_1$ particles.

Amounts of deposited total and traffic-related particle fractions in the road users’ respiratory systems in a 1-h period during the day and at night in the measurement periods in 2017 and 2020 are presented in Fig. 3.

4. Discussion

This study focuses on the COVID-19 pandemic lockdown introduced in the spring of 2020 as a unique opportunity to observe air quality changes in Lublin – a mid-size city in Central and Eastern Europe. Air quality in Lublin during its normal functioning in the spring of 2017 was adopted as the reference value. Exposure of drivers and pedestrians to aerosol particles on one of the main streets in the city has been analyzed. The mean mass of submicrometer and mean number of ultrafine particles inhaled and deposited in their respiratory system during the day and at night has been estimated, with consideration given to the doses of total and traffic-related particle fractions. The obtained results, as the once presented by Polednik (2021), show that the lockdown measures, due to a major reduction in car traffic in the city and to the changes of the vehicle fleet structure, resulted in a significant reduction in the concentration of the analyzed aerosol particle fractions in the vicinity of the monitored street. This specifically concerns vehicle-generated particles during the day and translates to significantly lower particle doses that are received by road users. Relatively high emissions from residential activity, especially emissions from residential heating furnaces which play a major part in the deterioration of the air quality in the city can be considered as a separate issue. Due to the absence of major industrial emission sources in Lublin, their contribution to the changes in the air quality in the lockdown period can be disregarded. The movement of air pollution from other areas can be considered as negligible as well due to the fact that the surroundings are rather rural. While discussing the obtained results the limitations of the performed studies must be underlined which, among other things, result from the lack of long-term measurements that would be unaffected by various influencing factors. It would be advisable to analyze greater data volumes from the pre-COVID-19 period as well as the lockdown period. Changes in metrological conditions that can have a significant impact on the pollution levels in the ambient air should also be taken into account.

A decrease in pollutant concentrations, including the concentrations of aerosol particles in the urban air during the COVID-19 pandemic has been reported in numerous studies worldwide. (Connerton et al., 2020; Xiang et al., 2020). It is mainly attributed to the reduction of traffic intensity, however, other reasons are also being taken into consideration. Wang et al. (2020b) found that the

Table 2

| Time | Particle fraction | Total | 2017 | 2020 | Traffic-related | 2017 | 2020 |
|------|------------------|-------|------|------|----------------|------|------|
|      | $d_p$ | $D$ | $C$ in $\times 10^3$ pt cm$^{-3}$ | $DD$ in $\times 10^9$ pt h$^{-1}$ | $C$ in $\times 10^3$ pt cm$^{-3}$ | $DD_T$ in $\times 10^9$ pt h$^{-1}$ |
| Day  | PM$_1$ | 0.165 | 0.16 | 31.27 | 5.17 | 0.202 | 0.14 | 16.77 | 2.43 |
|      | PN$_{0.1}$ | 0.046 | 0.47 | 9.39 | 4.44 | 0.047 | 0.46 | 4.34 | 2.02 |
| Night| PM$_1$ | 0.188 | 0.15 | 38.84 | 5.88 | 0.242 | 0.13 | 36.32 | 4.85 |
|      | PN$_{0.1}$ | 0.052 | 0.43 | 7.71 | 3.34 | 0.051 | 0.44 | 4.02 | 1.76 |

$C$ and $C - C_5$ in $\times 10^3$ pt cm$^{-3}$, $DD$ and $DD_T$ in $\times 10^9$ pt h$^{-1}$ for PN$_{0.1}$.
lockdown policy in Suzhou in China compared to the pre-COVID period resulted in a decrease of PM$_{2.5}$ and PM$_{10}$ by 37.2% and 38.3%, respectively. Studies of air quality in Dhaka City in Bangladesh carried out by Islam and Chowdhury (2021) indicated that during COVID-19 pandemic-induced lockdown PM$_{2.5}$ concentrations have been reduced by 26% as compared to previous year. Hudda et al. (2020) performed mobile monitoring in an urban area in Somerville in the USA in the COVID-19 pandemic period during which a 71% drop in car traffic and a 46% drop in truck traffic was observed. Results showed that total and traffic ultrafine particle number concentrations were respectively 60–68% and 45–69% lower during the lockdown as compared to pre-pandemic conditions. It was also underlined that during the lockdown a higher fraction of diesel vehicles in the fleet was observed. Chen et al. (2020) showed that in Shanghai, China, apart from the decline in transportation, the undertaken quarantine measures resulted in a decrease in industry emissions. They also suggested that the observed reductions in PM$_{2.5}$ concentrations can be mainly attributed to a decrease in concentrations of nitrate and primary aerosols. Li et al. (2021) presented similar conclusions and indicated that the lockdown to control COVID-19 in the North China Plain brought significant declines in air pollutant emissions. They noted that the haze and the persistent PM$_{2.5}$ pollution resulted from ongoing intensive industrial and residential emissions and increased loads of atmospheric oxidants which at that time were and continue to be a serious problem. Similarly, observations performed by Wang et al. (2021b) showed that despite the fact that anthropogenic emissions were greatly constrained during the COVID-19 lockdown, high loadings of PM$_{2.5}$ with secondary aerosols over northern China continued to increase. Sbai et al. (2021) investigated the changes of air quality in the Auvergne-Rhône-Alpes region in France during the implemented COVID-19 pandemic lockdown. They found that the restrictions of human activities, including a decrease in road traffic by 80% resulted in an increase of PM$_{10}$, and PM$_{2.5}$ levels by 23%, and 53%, respectively. Changes of air quality and its associated health effects in 31 provincial capital cities in China during the COVID-19 pandemic were investigated by Nie et al. (2021). They found that NO$_2$ reduction was the largest contributor to the health benefit, while PM$_{2.5}$ and PM$_{10}$ reductions were less significant.

Doses of particles deposited in the respiratory track of road users in 2017 presented in this paper are rather consistent with the ones reported in previous studies despite the fact that the measurements were carried out in different conditions, different measurement instruments and methodology were applied as well as a different result analysis was performed. For example, average deposited masses of submicrometer particles are similar to the ones estimated by Qiu et al. (2018). Number of ultrafine particles deposited in the respiratory systems of pedestrians in Rome in Italy estimated by Manigrasso et al. (2017) were higher only on workdays, and on weekends they were at an almost same level.

The particle concentrations measured in the present study and their estimated deposition doses take into consideration also the droplets exhaled by drivers, passengers and pedestrians mostly through the mouth but also through the nose. Therefore, they can also form a basis for estimating the infection risk of SARS-CoV-2 or other pathogens through aerosol transmission (Zhang et al., 2020; Garcia et al., 2021) for road users with or without masks. Measurements of variations of air particle size distributions, viral loads and interactions with other air pollutants in the ambient air seem to be study areas that urgently need further research. This follows, among other things, from the global spreading of highly pathogenic mutations of the SARS-CoV-2 virus and the potential spreading of other.

Fig. 3. Deposited doses of total and traffic-related PM$_{1}$ and PN$_{0.1}$ particle fractions in respiratory systems of road users during the day (D) and at night (N) in 2017 and 2020.
harmful or disease-causing microorganisms.

To sum up, the presented data could indicate that the lockdown period contributed to a significant improvement of the ambient air quality in Lublin. Such improvement resulted from a major reduction of car traffic and thus a reduction of the amounts of the emitted traffic-related fine and ultrafine particles. Undoubtedly, the positive health effects for road users and generally for the Lublin population arising from the lower amounts of the inhaled and deposited particles would have been greater if other intensive air contamination sources had been eliminated or reduced.

5. Conclusions

The carried out mobile and fixed-site measurements of aerosol particle concentrations in the ambient air in one of the busiest streets in Lublin during the COVID-19 lockdown in 2020 and in a comparable period in 2017 could indicate a significant reduction of the mass concentration of submicrometer PM$_{1}$ particles and number concentration of ultrafine PN$_{0.1}$ particles. Based on the obtained results one can also conclude that the share of traffic-related particles in such fractions has decreased several times. The greatest changes in the estimated amounts of particles inhaled by road users and deposited in their respiratory systems were observed during the day. The received doses of total PM$_{1}$ and PN$_{0.1}$ particles were over two times lower and the doses of traffic-related particles were over five times lower during the lockdown. Lower reductions of the inhaled and deposited doses were reported during the night and may indicate the existence of relatively intensive non-traffic emissions from residential activity. These emissions, weather conditions and other factors may affect the obtained results.

Comprehensive research comprising an analysis of more data from measurements carried out with the consideration of the possible weather condition changes is advisable. Such research should focus on the substantial impact of lockdown restrictions on the urban air quality as well as the health of the inhabitants, specifically road users.

CRediT authorship contribution statement

Bernard Polednik: Conceptualization, Methodology, Formal analysis, Investigation, Writing – review and editing, Visualization, Funding acquisition.

Author statement

The author confirms that this manuscript has not been published elsewhere in any form and it is not under consideration by another journal.

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Declaration of competing interest

The author declares no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2021.101233.

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