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LOW EMISSION DEVELOPMENT STRATEGIES AND SUSTAINABLE DEVELOPMENT GOALS

Short-term field research on air pollution within the boundaries of the large city in the Baltic region

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Abstract

Air quality in urban and suburban areas is strongly affected by the level of local urbanization, climatic conditions and industrial activity. Monitoring the main air pollutants such as nitrogen oxides, carbon monoxide and particulate matter may help control the most polluted areas of the site and take measures to reduce pollution. Uncontrolled emissions from other chemical pollutants, including volatile organic compounds and odorous contamination sources like ammonia, may cause both a chronic human disease and damage to flora and fauna. The conducted field research is aimed at determining air pollution within the areas of the large city (residential territory, recreation territory and the areas close to intense transport streets) polluted with the gaseous pollutants of varying nature (CO, NO_2, ozone, sulfur dioxide, VOC and NH_3) as well as particulate matter in different seasons of the year. Studies on Vilnius district air quality were carried out in 17 urban locations (sites) and based on two-phase measurements. The first phase was initiated in 2016–2017 and the second one took place in 2019–2020. It was observed that in the areas close to intense transport streets, the concentration of pollutants can increase more than 3 times, thus reaching up to 36.0 $\mu g/m^3$ of PM10 (particulate matter) and up to 48.0 $\mu g/m^3$ of nitrogen dioxide. During the summer period, ammonia concentrations can increase up to 3 times, reaching up to 11.0 $\mu g/m^3$ from farming and/or industrial activities.

Keywords Air quality · Gaseous pollutants · Particulate matter · Ammonia · City district

Introduction

Environmental quality assessment is important both for evaluating and/or analysing the ecological situation and for the long-term forecast of changes in situational dynamics. The issue of ambient air quality remains particularly relevant in urban and suburban areas considering an annual growth in the population, urban area expansion, an increase in road traffic intensity and the emerging new sources of air pollution.

Significant changes in air quality due to a decline in the industrial scale caused by the global COVID-19 quarantine were assessed (Kerimray et al. 2020). Changes were found to be less noticeable when the area was hardly urbanized and traffic flows were low. The performed studies showed that the level of primary pollution causes secondary pollution, which in turn exacerbates the environmental situation (Zheng et al. 2020). Thus, theoretical air pollution models estimating human migration have been developed for comparing the results of field research (Zeng and Bao 2021).

Air quality monitoring assists in taking control over possible environmental pollution. The level of air pollution determined with reference to field research findings provides the most accurate data on the situation of pollution in the investigated area. Only continuous selective

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monitoring of air pollution may provide the necessary information on identifying air pollution sources, reducing the resulting pollution and simulating the dispersion of air pollutants.

Road transport, energetic objects and industry are responsible for ambient air pollution. Polluted air is very noxious to human (Chen et al. 2012; Rushworth et al. 2014; Silva et al. 2013). Primary and secondary particulates are usually originated by natural sources such as wind-blown sands and sea spray particles. Main source of ambient air ozone is photochemical reaction of NO_X and VOCs at sunlight. As for Lithuanian cities $NO_{2,}$ SO_2, PM_{10}, CO and BTEX are mainly those caused by industry, energetics and transport (Iizuka et al. 2014). Air quality control is also performed for assessing the impact of air pollution on human health, the environment and climate in order to take necessary measures for protecting material, goods and living organisms. The EU Member States have defined maximum allowable levels (MACs) for some substances found in the air in the context of human health and plant protection. Council Directives—2000/69/EC (Król et al. 2012; Pekey and Yılmaz 2011), 96/62/EC (Adema et al. 2012; Słomińska et al. 2014) and 2008/50/EC (Šerevičienė et al. 2014)—are used for ambient air quality assessment and management. NO_2, SO_2, CO, O_3, PM_{10} and benzene values in ambient air were compared with limit values in line to 2008/50/EC directive. Toluene, ethylbenzene and xylenes (ortho, meta and para) are not included into the list of pollutants the amount of which in ambient air is regulated in agreement to European Union criteria.

Despite low quality of ambient air, monitoring of pollution is limited both in big urban areas and in small towns and rustic areas (Agrawal et al. 2021).

Lack of detailed data barely provides enough knowledge to determine the situation in the whole region.

Data on the Baltic region suggest that the use of coal as a fuel for households during the heating season is still remarkably widespread in the suburban area. The use of this type of fuel heavily pollutes the surrounding areas with carbon monoxide and carbon dioxide, sulfur dioxide and particulate matter (Wu et al. 2021). Particulate matter (PM_{10} and $PM_{2.5}$ in particular) contains a variety of pollutants, including sulphates, nitrates, ammonium salts, organic matter and heavy metals, causing significantly greater harm to human health than the traditional forms of pollutants (Xie et al. 2019).

Gaseous emissions (SO_2, NO_x etc.) are important precursors of the secondary inorganic aerosols (SIAs), namely, sulfate (SO_4^{2-}), nitrate (NO_3^-) and ammonium (NH_4^+) and could be emitted from stationary sources (fossil fuel combustion); ammonium emissions could be produced by livestock manure and fertilizer application.

Since the period of 1980s, the level of SO_x and NO_x pollution was the highest in Eastern Europe, although the emissions are decreased significantly until now up to 80% (Davuliene et al. 2021).

The assessment of air pollution in urban areas is often limited to monitoring CO gases in the atmosphere. Acute and/or chronic diseases and even death are caused by $PM_{2.5}$, PM_{10} and SO_2. The effects of nitrogen dioxide (NO_2) on the environment and human health are also harmful. In recent years, much attention has been paid to odorous pollutants caused by the contaminants arising from ammonia and volatile organic pollutants (VOCs) the most common of which are benzene, toluene, ethylbenzene and xylenes (BTEX). The intensity of the odours produced by the above introduced pollutants may vary subject to their concentrations and meteorological conditions (air temperature, wind direction and speed) and differ depending on the season of the year.

Air pollution measurements are frequently performed employing stationary and mobile devices. The latter are increasingly used due to equipment versatility. One of the most accurate, efficient and inexpensive techniques for determining air pollution presents the passive sorption method that applies to passive sorbents and allows examining air pollution conforming to the orientation of the pollution source in space. Passive sorbent exposure time ranges from 2 weeks to 1 month.

In order to perform a more detailed analysis of the return trajectories of air masses, it is necessary to evaluate the return trajectories of air masses at 3000, 1500, 500 and 50 m above the earth's surface. Different models are used to calculate the trajectories, e.g. NOAA AIR (National Oceanic and Atmospheric Administration, Air Resource Laboratory, USA) HYSPLIT and SILAM (Finnish Meteorological Institute) models.

The resolution and accuracy of the trajectory depend on the resolution of the wind field components, calculation methods and meteorological characteristics. Measurements are made at a certain frequency, e.g. every 3 h: at the selected height above the ground.

Models provide backward trajectories of air masses for a given coordinate at various heights. They use meteorological data that is measured in the x, y and z directions. The data is measured sequentially—in the form of a grid at a distance of 1° and is updated at a constant time interval. Mixing and stability coefficients are calculated from meteorological data using linear space–time interpolation. Both vertical and horizontal air mass mixing can be calculated in the models in order to provide the most accurate simulations of air mass movement. The stability of air masses in the underground layer is determined mainly by temperature and its variation, while other meteorological data have a greater influence in higher layers. In the model settings, it is possible to select the necessary coordinates, date with hourly accuracy, altitudes and options for the backward or forward air mass movement trajectories of the studied season. A more detailed analysis of the transport trajectories of return air masses was not applied to the selected air quality measurement points, due to the unavailability of the necessary data and the large volume of experimental research.

The maximum allowable levels defined for some substances and found in the air may cause a negative impact on human health and plants. Council Directives (2000/69/EC, 96/62/EC, 2008/50/EC) are used for ambient air–quality assessment and management. The concentrations of CO, NO_2, SO_2, PM_{10} and benzene in ambient air were compared with limit values in line to the Directive on ambient air and cleaner air for Europe (2008/50/EC). Toluene, ethylbenzene and xylenes (ortho, meta and para), are not included into the list of pollutants the amount of which in ambient air is regulated as reported by the criteria established by the European Union. The pollutants have been regulated since July 1, 2007 in keeping to the national criteria for Lithuania. CO, NO_2, SO_2, O_3, PM_{10} and BTEX were assessed at sixteen different places in all directions in Vilnius district for a one–year period (September 2019–June 2020) covering all seasons. Measurement sites were chosen for evaluating ambient air quality.

The principle objectives included quantitative analysis of the concentrations of CO, NO_2, O_3, SO_2, PM_{10}, BTEX and NH_3 in the areas close to potential emission sources and surrounding the Vilnius district, to assess the variation of pollution due to location and seasonality and evaluate the determined correlation between pollutants, taking into account the main groups of zones within the residential, recreation and close to intense transport streets.

Methodology

Study area

The study was carried out in Vilnius district, Eastern Europe, Lithuania and counted four permanent air quality monitoring places installed in the city (three places were set up close to the intense traffic road and one in the Old Town). No monitoring place was established on the cityside or in the district.

In line to Lithuanian State Enterprise Centre of Registers, a population of 106,957 inhabited Vilnius district in 2021. The area of Vilnius district covers 2129 km^2.

The average perennial climatic data on Vilnius district show a temperature of − 5.5 °C in January (winter/cold period), a temperature of + 18.0 °C in July (summer/warm period) and approximate annual of 7.0 °C under the precipitation of 640 mm (annual).

Southwest and west winds prevail in Lithuania, which bring air masses from eastern and central European countries—the Czech Republic, Poland and Germany. During the analyzed period, southwest and west winds prevailed, which could bring air masses from the mentioned European countries. Backward air mass transfer trajectories were not used in this study. This method is relevant for the analysis of long-distance transmission, the territory of the Vilnius district is relatively small, so it was abandoned for this case.

Studies on air quality in Vilnius district were conducted in 17 urban locations (sites). The map of the selected sites in Vilnius district is given in Fig. 1.

Vilnius district municipality is one of the largest municipalities in Lithuania. The area occupies 2129 km^2 area and is divided into 23 sub-districts. The district from the north, south and east surrounds the Lithuanian capital Vilnius, with a developed public and business, rural infrastructure, which is able to harmonize and develop dynamically, attract new investment and ensure a high quality of life and environment for everyone. The territory of Vilnius district borders on the Republic of Belarus in the east. Vilnius district is dominated by rural areas (a total of 1163 villages). The number of people living in villages in Vilnius district reaches 95 percent in municipal population, while on average in Lithuania, 33 percent population lives in villages; the population of Vilnius district was 100,146 citizens in 2020 year.

Measurement sites (a total of 17, including one for ammonia) were selected as representing recreation, residential and transport impact territories in Vilnius district. The site (No 17) was selected to analyze the impact of potential pollution from poultry farming industry. Potential emission sources in Vilnius district is presented in Table 1; their locations are indicated in Fig. 1a.

The description of all measurement sites is presented in Table 2. The location of the sites was chosen according to the location of the largest towns and settlements in terms of population, and their number was chosen in proportion to the number of inhabitants, the main sources of pollution, among which the most distinguished roads are motorways. The aim was to carry out studies in different types of zones, the location of which is as close as possible, with the possibility to compare their pollution results with each other and to assess the source of the pollution.

First air quality measurements were carried out from June 2016 to March 2017. The second phase of the research was conducted from September 2019 to June 2020. During the first phase of research in 2016, air quality analysis was carried out in a narrow format, only in winter and summer, and the level of ammonia pollution was not assessed either. However, based on the results of the study, it was decided to conduct an analysis during all seasons, as well as the study of ammonia at a potential source of pollution. In this article, it is customary to consider the results obtained in the late period, i.e. 2019–2020, and for the dynamics of change, some data obtained in 2016 are presented. The reason for the re-analysis is that most of the population of the entire

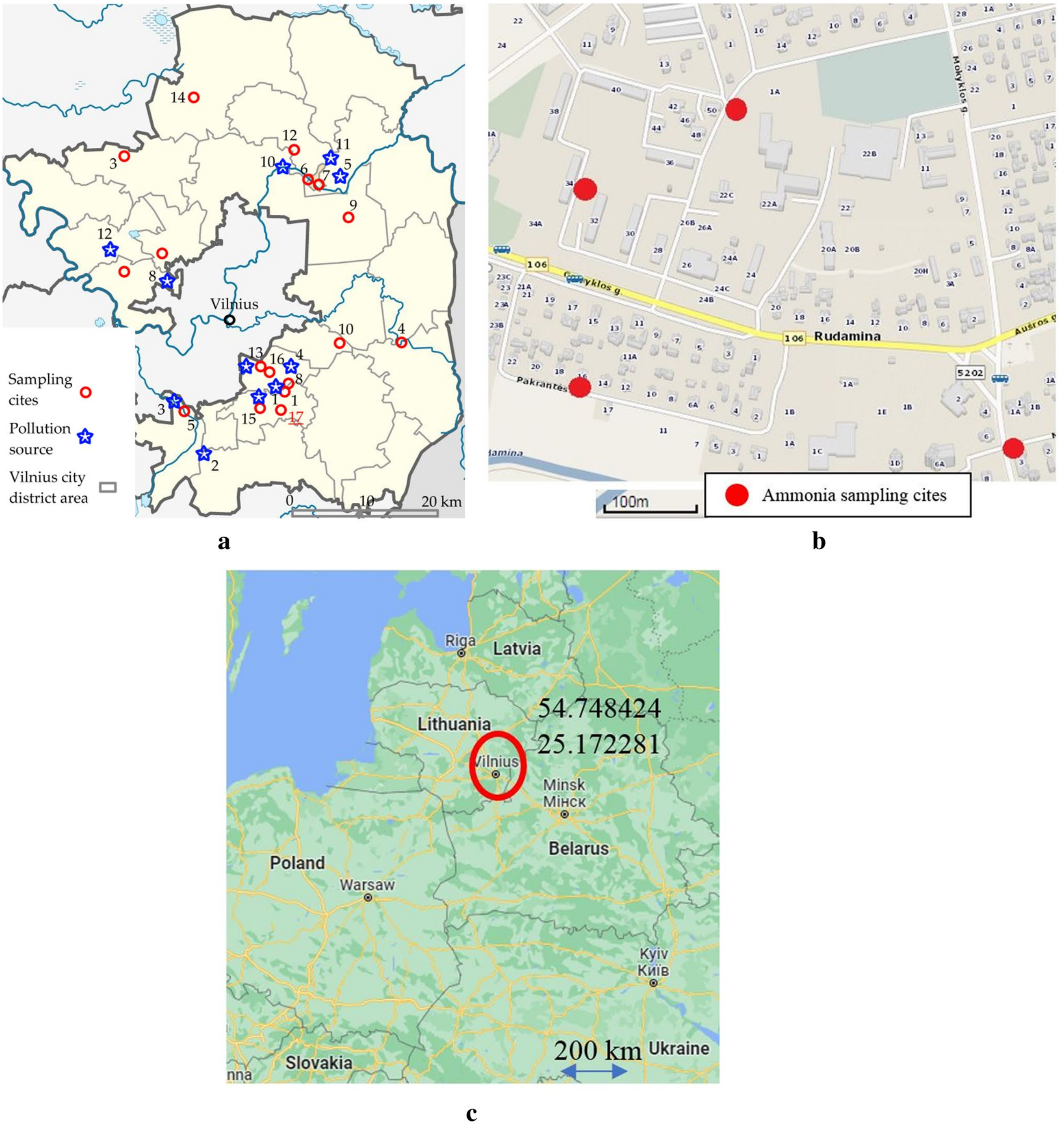


Fig. 1 The research sites of air quality and pollution sources (**a**) and ammonia at a potential pollution source (**b**) in the area of Vilnius District Municipality in Eastern Europe scale (**c**)

country equips housing in the city area, and not in the centre of the city itself, which contributes to an increase in communication between the city and its region.

No significant changes occurred in this territory during the period from 2016 to 2020, e.g. forest cover increased by 0.7 percent, population decreased by almost 5000, individual cars increased by about 8600 and construction activity objects increased by about 100 units. Legally since 2011, companies are prohibited from using fuel oil; this has led to even greater reductions in sulfur dioxide emissions. In the period between 2016 and 2020, several major infrastructure projects for the city and region of Vilnius were put into operation. Among them are the southern and western bypass roads. These vehicular routes have significantly

Table 1 Potential emission sources in Vilnius district, their type and area

No	Type of industry/manufacturing source of air pollution	Location relative to the centre of Vilnius	Area, m^2
1	Boiler house No. 1 (biofuel and natural gas)	South-Est	1300
2	Boiler house No. 2 (biofuel and natural gas)	South	600
3	Agricultural production (growing vegetables)	South-West	138,800
4	Service sector (production of packaging)	South-Est	11,300
5	Production of building materials (expanded polystyrene)	Nord-Est	65,600
6	Agricultural production (mushroom cultivation)	Nord	9980
7	Production of building materials (expanded polystyrene)	South-Est	3000
8	Service sector (printing and printing)	Nord-West	5500
9	Animal husbandry (poultry farm)	South-Est	1,060,000
10	Production of textile materials	Nord-Est	13,350
11	Production of building materials (woodworking)	Nord-Est	16,200
12	Recycling and production of plastic	Nord-West	164,400

Table 2 Measurement sites

[No of the sites], coordinates		
Residential territory	Recreation territory	Areas close to intense transport streets
[O2] Residential quarter, traffic pollution	[O7] Residential quarter, traffic pollution	[O1] Residential quarter, impact of road pollution
[O3] Residential quarter, traffic pollution	[O12] Residential quarter, traffic pollution	[O5] Residential quarter, industrial and transport pollution (agricultural and power plant industry)
[O4] Residential Quarter, pollution from road and rail transport	[O16] Residential Quarter, industrial and transport pollution	[O6] Residential quarter, industrial and transport pollution (Woodworking, Building and textile materials production)
[O8] Traffic pollution		[O10.1] Northern side of the airport
[O9] Residential quarter, background concentration		[O10.2] Western side of the airport
[O13] Residential quarter, pollution from road and rail transport		[O10.3] Southern side of the airport
[O14] Residential quarter, traffic pollution		
		[O10.4] Eastern side of the airport
		[O11] Residential quarter, industrial and transport pollution (recycling and production of plastic, printing goods)
		[O15] Residential quarter, traffic pollution
Ammonia		
[O17.1] Northern side of poultry farming 54.593489, 25.339479 (apartment buildings)		
[O17.2] Eastern side of poultry farming 54.594855, 25.342759 (areas close to the gymnasium and kindergarten)		
[O17.3] Northern side of poultry farming 54.594808, 25.342757 (private household blocks)		
[O17.4] Eastern side of poultry farming 54.591372, 25.339574 (private household blocks)		

reduced traffic congestion in the city itself, but increased traffic flow in the area. The industrial sector within the city did not change much; however, it is noticeable that large departments of sorting goods have moved warehouses to the city area along the perimeter.

The air polluted with NH_3 was measured at *SC Vilniaus Paukstynas*, a potential source of an unpleasant odour in the area of Vilnius District Municipality (Fig. 1b, Table 2). The area of the Rudamina poultry farm is 106.7 ha. Broilers are raised in the poultry house, raised on sawdust bedding without cages. Broilers are grown from 1-day-old chickens to 40–49 days old. During the year, 6–7 cycles are grown in each aviary. The maximum number of reared birds at one time is 1,456,000 units.

The concentrations of gaseous pollutants (CO, NO_2, SO_2, O_3) were detected at a mobile laboratory applying analyzers. The mobile laboratory is installed in the car. In order to avoid contamination from the car itself, a generator was used for power, which was installed on the side in the direction of the wind from the laboratory at a distance of 100 m. The detailed information about instruments is presented in Table 3.

The air quality assessment period is presented in Table 4. BTEX and NH_3 were analyzed employing the diffusive sampling method, and the concentration of inhalable particulate matter (PM10) was calculated using analyzer MP101M. The experiments were carried out continuously for each pollutant three times per measurement site and/or exposing three parallel diffusive samplers.

Following exposure, diffusion samplers were analyzed in an accredited laboratory of *Gradko JSC* (Great Britain) thus determining the quantity of BTEX and NH_3 (Lithuanian Air Monitoring System, 2010). Tube made from polymer fitted with thermoplastic rubber caps. The cap contains the absorbent. A one-micros porosity filter is fitted to absorb the pollutant. All diffusion samplers are suitable for carrying out spatial or localized assessments for specific pollutant in ambient air. Typical exposure period is 2–4 weeks. For this study, sorbents were used whose exposure period is 2 weeks, i.e. 14 full days. This period is indicated and taken into account by the manufacturers of these sorbents, and according to the methodology of an accredited laboratory, the level of contamination for each pollutant is recalculated. No other analyzers were used for comparison by these pollutants. In line to air quality directive 2008/50/EC, the results of indicative measurements shall be considered for assessing air quality with respect to limit values. For indicative measurements, minimum time coverage is 14% that provides 8 weeks evenly distributed over the year. Time for applied measurements was in consonance to the established requirements. Therefore, the obtained results can be compared with the defined limits for the measured pollutants. The samplers in casings were fixed at 3–4 m above the ground. The area of sampling exposure was open, free from buildings, trees and other objects and at least 1 m from any structures that could disrupt airflow. PM_{10} was measured applying the beta radiation absorption (ISO 10473) method on Environment S.A. Model MP101M PM_{10} Beta Gauge Monitor (France) device for a period of 8 h at an average flow rate of 1.0 m^3/h. At each measurement site, an average value of PM_{10} was calculated.

The settlement of Rudamina has been selected as the area where the main poultry company of Vilnius city operates and as one of air quality measurement sites. The residents of the settlement constantly make complaints about unpleasant odours emitted from the object, which dramatically increases

Table 3 Information about instruments at a mobile laboratory

Equipment name	Detection method	Pollutant	Measurement range: minimal detectable limit–maximum limit	Repeatability	Span drift
Environnement S.A. AC 32 M	Chemiluminescent	Nitrogen dioxide (NO_2)	4 ppb–5050 ppm	1%	< 1%/7 days
Environnement S.A. AF 22 M	UV fluorescent	Sulfur dioxide (SO_2)	1 ppb–10.000 ppm	1%	< 1%/24 h
Environnement S.A. CO12	Gas filter correlation	Carbon monoxide (CO)	50 ppb–200 ppm	1%	± 1%/15 days
Environnement S.A. MP101M	Beta gauge monitor	Suspended particulate (PM_{10})	6 μg/m^3–0.500 mg/m^3	1%	0.5 μg/24 h
Environnement S.A. O3 42 Module	UV photometric	Ozone (O_3)	1 ppb–10.000 ppm	1%	< 1%/7 days

Table 4 Air quality within the Vilnius district assessment period

Season (quarter)	Pollutant	Period of measurements
Autumn (IV quarter)	CO, NO_2, SO_2, O_3, PM_{10}	September 6, 2019–September 18, 2019
	BTEX, Ammonia	September 11, 2019–September 25, 2019
Winter (I quarter)	CO, NO2, SO2, O3, PM_{10}	March 22, 2016–March 29, 2016 January 20, 2020–February 29, 2020
	BTEX, Ammonia	January 22, 2020–February 5, 2020
Spring (II quarter)	CO, NO2, SO2, O3, PM_{10}	April 1, 2020–April 10, 2020
	BTEX, ammonia	April 1, 2020–April 15, 2020
Summer (III quarter)	CO, NO2, SO2, O3, PM_{10}	June 22, 2016–June 29, 2016 June 15, 2020–June 25, 2020
	BTEX, ammonia	June 16, 2020–June 30, 2020

during the summer period. The relevant studies provide that the current odour standardization is regulated by the Lithuanian Hygiene Standard HN 121:2010 *Limit Value of the Odour Concentration in the Residential Ambient Air* and *The Regulations of Odour Control in the Residential Ambient Air*. As reported by the introduced documents, the limit value is equal to 8 ouE/m^3 (European odour units). In the future, the value is expected to rise and make as high as 5 ouE/m^3. Thus, ammonia concentration was estimated every 3 months next to the measurement site of residential blocks or private households downwind of the poultry house as the potential source of air pollution.

Statistical analysis and data quality

Three samples were taken at each measurement site. A blank sample was used as a control unit. Descriptive statistical analysis was employed (mean, standard deviation interval and Pearson coefficient) applying Excel 2016. The significance of association (p) was accepted as statistically significant at the alpha level of < 0.05. The place, height and duration of sampling, storing and transporting samples were carried out conforming to requirements for standards. Accredited laboratory *Gradko JSC* (Great Britain) analyzed the obtained air samples.

Results and discussion

The research findings of air pollution in the area of Vilnius District Municipality have been compared considering all seasons, including autumn 2019 and winter–summer 2020. The investigation of the concentrations of pollutants was performed once a season. The presented figures provide only the number of the research site without further detail, and the obtained results are grouped at the measurement sites in residential and recreation territories and those next to heavy traffic roads, respectively.

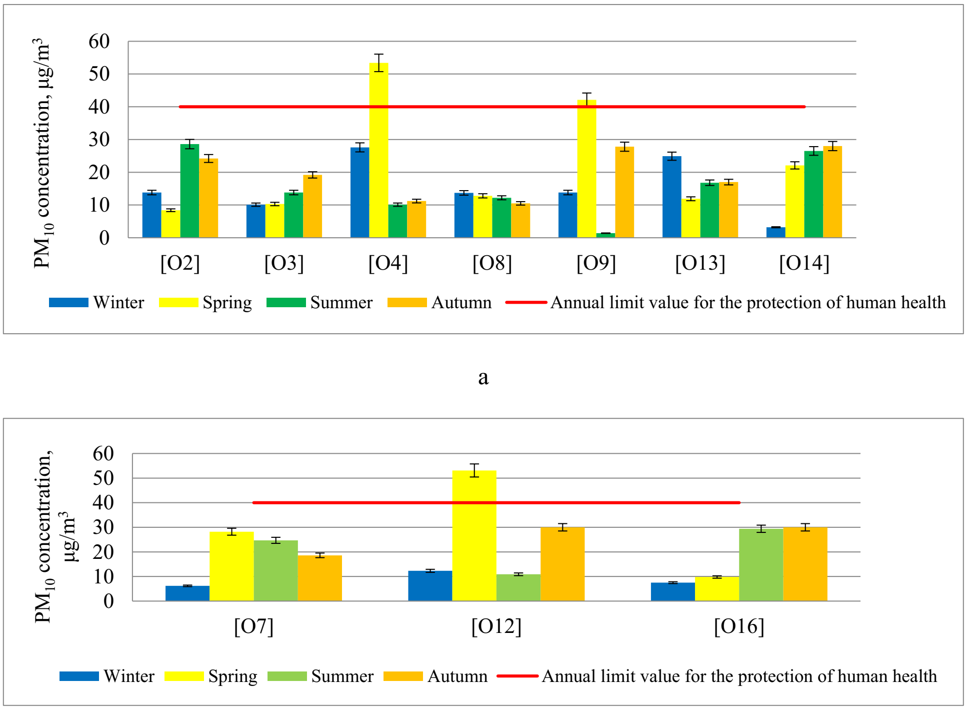
In 2019, Lithuania calculated an average of 466 cars per 1000 inhabitants. The number of cars in both Lithuania and Vilnius district grows every year thus increasing air pollution; however, stricter requirements for the amounts of pollutants (latest euro standards) emitted from cars into ambient air are reducing emissions. Rising pollution caused by road transport is successfully reduced through the replacement of gravel roads with hard road surfaces and watering the streets of cities. Also, making detours decreases a negative impact of transport on human health. Air pollution from rail transport is cut electrifying certain railway lines conforming to the EU standards and tightening standards limiting the concentrations of the pollutants emitted by rolling stock into the air. Engineering solutions, e.g. detours, do not reduce emissions from transport, but they do reduce air pollution in areas with high population density and/or areas with higher levels of air pollution. This is justified and may be recommended in cases where air pollution is transferred to less populated areas and areas with low air pollutant concentrations and when air pollution levels increase, air pollutant concentrations will not exceed permissible limit values, thereby reducing the negative impact of air pollutants to the health of a certain part of people.

Variations in the concentration of particulate matter (PM$_{10}$) are shown in Fig. 2 and Table 5.

Emission from car traffic or increased pollution is one of the main sources of pollution with particulate matter in the open environment. The conducted studies have disclosed increased PM$_{10}$ concentration in the highest intensity roads compared to the findings received in other types of zones where the values ranged from 20.2 to 36.0 μg/m^3 and standard deviation (SD) was equal to 1–1.8 μg/m^3. The installation of passive sorbents taking place prior to the heating season in the early autumn avoided the effects of additional pollution. PM$_{10}$ concentration was very low at some measurement sites related to transport units and varied between 4.2 and 7.4 μg/m^3 (No 1 and 15), which was caused by the decreased flows of cars (5–36 pcs) and heavy vehicles (up to 6 pcs) determined within a period of 1 h, SD was equal to up to 0.4 μg/m^3. During the winter season, the concentrations of all tested pollutants dropped by no more than 1.6 times, and PM$_{10}$ concentration was highest compared to the annual average. During the wintertime, additional pollution was initiated by the activity of district boilers used for heating, and traffic flows decreased by approximately 20–30% (compared to the autumn season). As for the urban area, heat energy for multi-apartment buildings and a part of individual residential houses was supplied from centralized district heating energy systems. However, most of the residential houses are individually heated by gas or solid fuel boilers. In Vilnius district, natural gas used for heat production makes up around 78% of fuel balance, whereas coal takes 11% and the rest is biofuel and liquefied gas.

Emission results changed moderately comparing the results of monitoring in 2016 and those for the period of 2019–2020. PM$_{10}$ concentration varied from 8.7 to 39.1 μg/m^3 with an average value of 18.71 μg/m^3 (SD was equal to 0.9 μg/m^3), i.e. only 1.015 times lower than that in 2019–2020. The minimum value of PM$_{10}$ concentration was equal to 8.7 μg/m^3 (summer average value made 13.03 μg/m^3) in June 2016 and a maximum of 39.1 μg/m^3 (winter average value reached 24.39 μg/m^3) was detected in March 2016. Overall, 100% recorded values of PM$_{10}$ were found within the permissible limit of 40 μg/m^3 unlike the case in April 2020 with four results that exceeded. The average PM$_{10}$ concentration in Vilnius district was low throughout 2016, but there was the same, as in 2019–2020, a sudden increase in the winter season

Fig. 2 The annual concentration of particulate matter (PM_{10}) in the ambient air of Vilnius district: **a** residential territory; **b** recreation territory



a

b

Table 5 Particulate matter (PM_{10}) concentration (in µg/m^3) measured in the areas close to intense transport streets

Season/site	[O1]	[O5]	[O6]	[O10]	[O11]	[O15]
Winter	31.6	14.8	9.4	18.3	10.2	33.0
Spring	23.3	12.0	34.5	33.3	10.8	6.6
Summer	12.9	26.3	6.2	3.2	20.8	13.7
Autumn	4.2	23.8	26.4	20.2	36.0	7.4
Annual limit value for the protection of human health	40					

was observed due to the cumulative effect of house heating, energetic objects and transport and because of an adverse effect on the dispersion of pollutant meteorological conditions (prevailing calm conditions).

Between 2005 and 2019, the emissions of particulate matter declined considerably by around 29% in the EU-27 Member States. The required decrease is significant for a number of countries, including 10 of those demanding reductions in more than 30% (European Environment Agency 2021).

The concentrations of air pollutants in the residential areas studied within the January–February period also increased compared to the values of the autumn season. However, a significantly larger change was monitored in the blocks of private households lacking district heating. In spring, the heating season continued along with the conducted research, but in the majority of sites, temperature was twice as high (average of 6 °C) as that in winter (average 3 of °C). Pollution from road transport peaked at several measurement sites, but the concentration of particulate matter in residential areas increased the most thus making 42–53 µg/m^3. It is assumed that an increase in pollution following the winter season contributed to the current pollution due to the level of pollutants generated by private houses and centralized boilers because of the ongoing heating season. Traffic flows were noticed to be rising, which also might increase air pollution.

Variations in sulfur dioxide (SO_2) concentration are shown in Fig. 3 and Table 6.

The detection of sulfur dioxide may signal the sources of heavy hydrocarbon combustion, high emissions from high-traffic vehicles and pollution from industrial sites. The estimated level of the concentration of the above introduced pollutant was found to be low; for instance, the average SO_2 concentration varied in different seasons of the year and

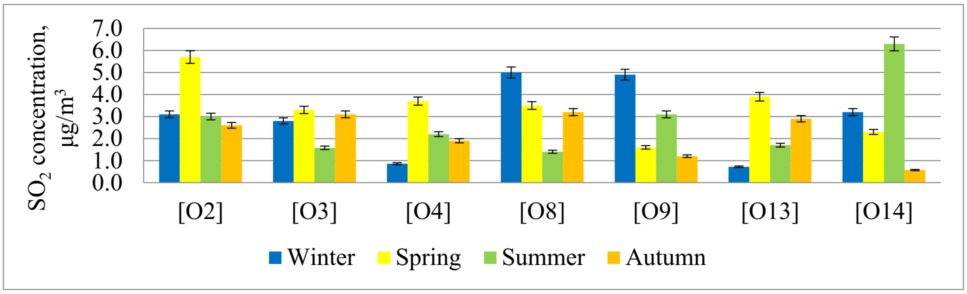


Fig. 3 Sulfur dioxide (SO_2) concentration in the ambient air of the residential territory in Vilnius district

Table 6 Measured SO_2 concentration (in μg/m^3) in the recreation territory and areas close to intense transport streets

Recreation territory						
Season/site	[O7]		[O12]		[O16]	
Winter	2.8		3.8		1.9	
Spring	2.2		2.1		3.0	
Summer	3.6		4.4		1.9	
Autumn	1.8		0.7		0.3	
Areas close to intense transport streets						
Season/site	[O1]	[O5]	[O6]	[O10]	[O11]	[O15]
Winter	3.1	6.2	2.4	5.1	5.6	0.59
Spring	2.2	3.4	4.5	1.7	3.6	3.6
Summer	2.0	1.7	5.4	6.2	4.6	0.9
Autumn	2.2	2.7	2.8	2.0	2.4	2.9
Annual limit value for the protection of human health	20.0					

made 2.1 μg/m^3 in autumn, 3.3 μg/m^3 in winter, 3.1 μg/m^3 in spring and 3.1 μg/m^3 in summer. The maximum SO_2 concentration level took in summer due to intense traffic flow comparing to other seasons; the cite O14 is located near to intense interurban road. This level is decreasing and the concentration decreased triple from 2016 till 2020. The average concentration of all seasons is 2.9 μg/m^3. The abovementioned pollutant was higher than those set in recreation territories or in the living environment at almost all measurement sites related to heavy traffic flow (measurement sites 5, 6, 10 and 11). SO_2 concentration was found to be highest in winter and especially summer. The carried out research showed that ambient temperature (21–28 °C) exceeded the normal one at these sites during summertime and wind speed was constant at around 2.5–3 m/s. One of the largest traffic flows was recorded particularly at these sites, and the most intense one was set at measurement site 10 where 66 vehicles had passed within a period of 1 h. Measurement site 13 is accepted as an exception representing the residential area; however, in the case of extremely intensive traffic flow (180 pcs / hour), SO_2 concentration was slightly higher than the average of all studies, and the highest one was estimated during the spring season (3.9 μg/m^3).

Ambient SO_2 concentration varied from 0.3 to 18.0 μg/m^3, an average was 3.4 μg/m^3 in 2016 in Vilnius district. The minimum value of SO_2 concentration was equal to 0.3 μg/m^3 (average winter value made 1.5 μg/m^3) in March 2016 in contrast with that of 3.3 μg/m^3 for the case in the 2019–2020 period. The maximum emission was equal to 18.0 μg/m^3 (average summer value made 5.3 μg/m^3) detected in June 2016 (for example, 3.1 μg/m^3 for the period 2019–2020).

In line to the data provided by the European Environment Agency, 27.7 kt (EEA33) and 25.6 kt (EU28) of sulfur dioxide were emitted in the European Union in 1990, whereas in 2011, the index identifying the remaining part of pollutants made 26.5% and 17.9%, respectively. In 2020, conforming to the Gothenburg Protocol, the annual target value was hardly realized due to its index equal to 12.5 and the EU28 index making 32.7. SO_2 emissions declined in the EU27 Member States by 76% for the period from 2005 to 2019.

Higher SO_2 concentration was observed at an ambient temperature above 28 °C. In cold weather (winter) but at a relatively low air temperature of around 2 °C, an increase can be observed at the measurement sites in the areas close to the residential blocks due to the increased use of liquid fuel (diesel) for heating.

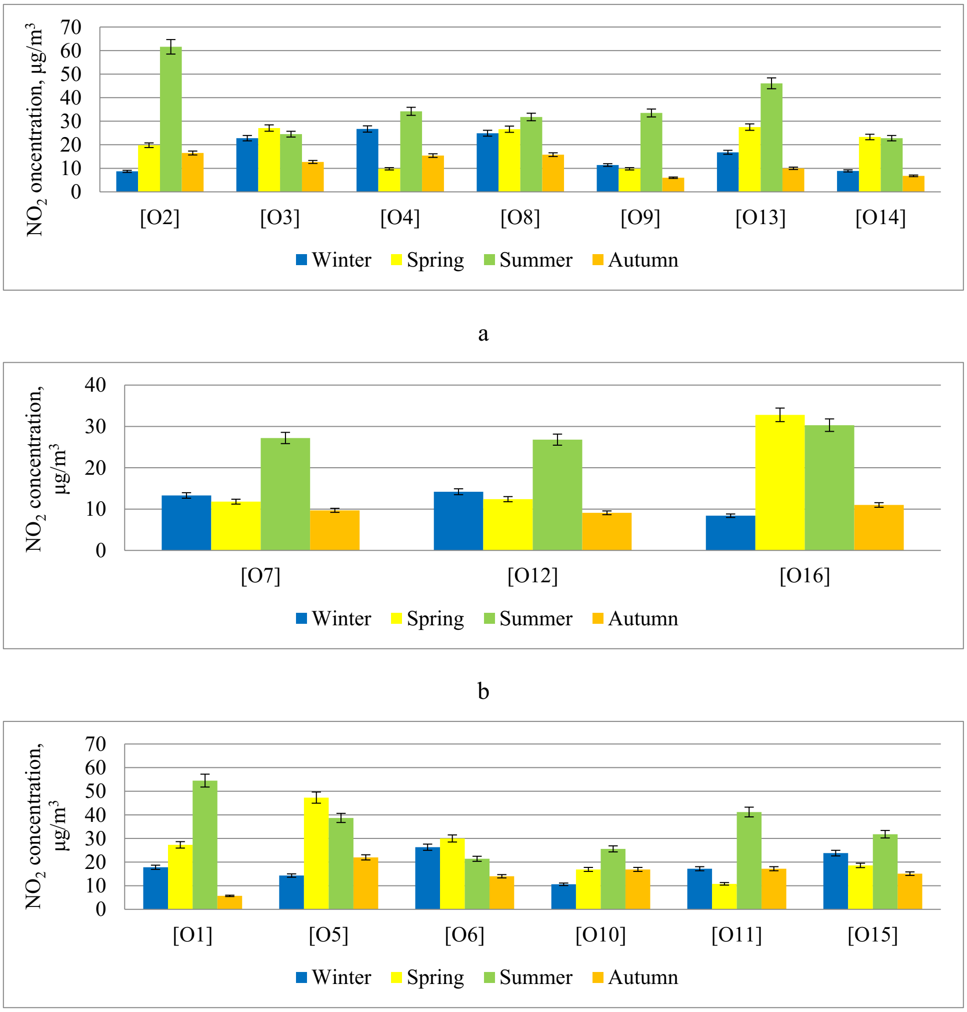
Variations in nitrogen dioxide (NO_2) concentration are shown in Fig. 4.

Nitrogen oxides act as one of the components in emissions, particularly during the high-temperature combustion of gaseous fuels. The improper handling and storage of organic waste in open air due to the activity of microorganisms during the decay process may increase the concentration of nitrogen oxides and other pollutants as well as cause unpleasant odours. Figure 4 shows NO_2 concentration exceeding the value of 30.0 μg/m^3 established for vegetation protection and found in 50% of all measurement sites during the summer season when the average air temperature made 23.2 °C at a variable wind speed of 2.5–2.7 m/s. A significant increase in NO_2 concentration was observed at the measurement sites near the motorways. When the traffic is more than 60 vehicles/h, the concentration of nitrogen dioxides increased more than 1.4 times. Although concentration was also high in spring, however, it was 1.5 times lower than that in summer. The level of pollutant concentration in residential areas changed insignificantly both in summer and the rest of the seasons.

The minimum value of NO_2 concentration in 2016 was found to be equal to 3.5 μg/m^3 in March 2016 (5.7 μg/m^3 in September 2019), and an average of winter 2016 made 9.6 μg/m^3 (16.6 μg/m^3 in 2020). The recorded maximum value of NO_2 equalled 19.0 μg/m^3 (average summer value reached 13.7 μg/m3) in June 2016 and was 3.2 times lower than that in summer 2020.

The potential sources of nitrogen dioxide pollutants are slightly different from those of particulate matter or sulfur dioxide, and therefore, no overall correlation was found, except that pollution was higher in spring and summer rather than in other seasons. The formation and accumulation of pollutants close to roads are determined by the specific relief of Vilnius district. The Medininkai Upland rises in the east of Vilnius District, the Dainava Lowland occupies the southeast and the Aukstaiciai Upland is in the northwest. Thus, the pollutants generated in the south-eastern part of the city accumulate directly in this area, and those transferred from other areas may accumulate in this zone and do not move further. Neris, Vilnele and Voke valleys are located in the central and eastern part of Vilnius district, which create a greater mix of traffic flows in this zone, and therefore, the spontaneous clean-up of the environment is more intensive than elsewhere. Meanwhile, the second zone of pollutant accumulation is the northern

Fig. 4 Nitrogen dioxide (NO_2) concentration in the ambient air of Vilnius district: **a** residential territory; **b** recreation territory; **c** areas close to intense transport streets



a

b

c

part of Vilnius district characteristic of lowlands. The lowest measurement site of Vilnius district is at the western border of the district in the Neris Valley.

In 1990, the European Union generated 18.3 kt (EEA33) and 17.3 kt (EU28) of nitrogen oxides, while in 2011, the remaining quantities (indices) accounted for 56% and 51%, respectively. In 2020, Gothenburg Target Value Index was equal to 38.8 and was failed to be reached under the EU28 index of 52.4.

EEA33 NO_x emissions decreased up to 40% in 1990–2011 period. Decreased NO_x emissions were declared for the bigger part of countries, especially in road transport sector (up to 47% by total) and energetics (27%).

The initial chemical compound that forms during combustion and other processes and causes the formation of climate change greenhouse gases (CO_2) is presented by carbon monoxide (CO) the variations of the concentration of which are given in Table 7.

Assuming that carbon monoxide is emitted from the anthropogenic sources of pollution, a particularly high concentration of CO is observed during the winter season. Evidence has been obtained at measurement sites 2, 3 and 11 belonging to household and heavy traffic areas. A similar trend was noticed for SO_2 concentration. The meteorological conditions of the carried out research included the wind of 2–2.5 m/s under the extremely low or insignificant dispersion of pollutants. Slightly lower CO concentration was found at one of the measurement sites of recreation territories and household areas during autumn and spring seasons. Traffic flows recorded in the household area reached up to 60 vehicles per hour. An increase in CO concentration may frequently correlate with PM_{10} concentration values; however, this dependence was found to occur only in autumn. None of the received PM_{10} values was close to the applicable annual limit value of 40.0 µg/m^3, which indicated that the resulting pollution was insignificant.

The values of CO concentration varied from 0.7 to 2.1 mg/m^3 under the average value equal to 1.3 mg/m^3 and the minimum value of 0.7 mg/m^3 (average winter value made 1.2 mg/m^3 under a value of 0.8 mg/m^3 in winter 2020) in March 2016. The maximum value of 2.1 mg/m^3 (average summer value reached 1.36 mg/m^3 under a value of 1.1 mg/m^3 in summer 2020) was detected in June 2016.

Freight CO_2 emissions are expected to rise 22% from 2015 to 2050. Return to 'normal' after the pandemic will miss CO_2 reduction targets. With increased ambition, a 72% cut in freight CO_2 is possible over the next three decades.

The estimated freight transport emissions under the current policies making 105 by 2030 and 120 by 2050 are current policies (recover scenario) compared with 2015 (under the index equal to 100); those making 85 by 2030 and 35 by 2050 are ambitious policies (reshape scenario) and 65 by 2030 and 30 by 2050 are ambitious policies, leveraged recovery (reshape + scenario).

Road transport is responsible for 65% of freight emissions. The majority of emissions come from road and urban logistics, critical front to reduce emissions. Its share will increase in all scenarios by 2050. The total CO_2 emissions from freight transport under the current policies will be equal to around 2500 Mt CO_2 from the road (including urban logistics) and 600 Mt CO_2 from the Sea region by 2050.

Tropospheric ozone is one of the main agents which impacts on the breathing system and causes more diseases such as asthma and bronchitis (Kahle et al. 2015).

Table 7 Carbon monoxide (CO) concentration in the ambient air of Vilnius district (mg/m^3): residential territory; recreation territory; areas close to intense transport streets

Residential territory							
Season/point	[O2]	[O3]	[O4]	[O8]	[O9]	[O13]	[O14]
Winter	3.0	2.8	0.4	0.2	0.3	0.6	0.5
Spring	0.5	0.2	0.3	2.1	0.2	0.2	0.2
Summer	0.9	0.5	1.0	0.7	0.8	0.2	0.1
Autumn	0.2	0.1	1.2	0.1	0.5	0.2	0.5
Recreation territory							
Season/point	[O7]		[O12]			[O16]	
Winter	0.3		0.4			0.3	
Spring	0.4		0.2			0.4	
Summer	0.9		0.8			0.2	
Autumn	0.1		2.6			0.2	
Areas close to intense transport streets							
Season/site	[O1]	[O5]	[O6]	[O10]	[O11]	[O15]	
Winter	0.4	0.4	0.3	0.3	2.2	0.7	
Spring	0.2	0.2	0.2	0.4	0.4	0.5	
Summer	0.5	0.2	1.3	0.8	0.1	0.3	
Autumn	0.1	0.6	0.03	0.1	0.4	0.6	
Annual limit value for the protection of human health	10.0						

Ozone production increases significantly when exposed to solar radiation and immediately after lightning discharge. Ozone can also undergo photolysis in the presence of solar radiation, having its concentration decreased. Ozone production depends on the presence of precursors (NOx and VOCs) and adequate weather conditions, such as increased solar radiation. Seasonal variations in the concentration determined by studies are provided in Table 8.

O_3 concentration compared to the established limit value (120 µg/m^3) was found to be lower but close to the set limit. No significant differences between different periods were observed, but the values were slightly higher in spring and autumn. Similar variations in the concentrations of pollutants PM_{10} and O_3 at measurement sites 4, 6, 10 and 12 were detected in spring. Irrespective of the type of the zone, ozone concentration remained similar at these sites and no significant effects of meteorological conditions were noticed.

O_3 concentration varied from 43.5 to 110.9 µg/m^3 with an average value of 71.9 µg/m^3 during the first phase (in 2016) and was 1.52 times lower than that during the second phase in 2019–2020. The minimum value of O_3 concentration was recorded to be 43.5 µg/m^3 (19.4 µg/m^3 in 2020). The maximum value of 110.9 µg/m^3 (average winter value made 67.6 µg/m^3) was detected in March 2016, and the average summer value made 76.1 µg/m^3, which was 1.19 times lower compared with the period of 2019–2020.

The reactions of underground ozone formation and decay are complex. They depend not only on the concentration of individual ozone precursors (nitrogen dioxide, VOCs), but also on their ratio. Many other chemical compounds are also involved in these complex processes. When unfavourable conditions for the dispersion of pollutants occur, the levels of nitrogen dioxide and ozone concentrations in the air may rise during the warm season. Near streets with heavy traffic, the concentration of ozone in the air is lower, because nitrogen monoxide destroys ozone and because high concentrations of sulfur dioxide slow down the process of ozone formation, we can partly explain that the annual averages of ozone concentration are higher in cleaner areas than in more polluted (urbanized) area territories (Baruah et al. 2022; Derwent et al. 2015).

Evaluating the obtained results, one of the assumptions is that the aforementioned increase in ozone concentration was caused both by natural processes in this region due to the effects of solar radiation and the formation of discharges during thunderstorms, but also due to the transport of distant air masses from neighbouring European countries. Ozone in the upper layers of the atmosphere protects the earth from the harmful effects of the sun's ultraviolet radiation, but ozone in the air layer close to the ground is considered a pollutant because its higher concentrations are harmful to human health and the environment. Ground-level ozone is not directly emitted into the atmosphere, but is a secondary pollutant that results from complex photochemical reactions when nitrogen oxides and hydrocarbons in the atmosphere, the main sources of which are the internal combustion engines of vehicles and industry, react with each other under the influence of sunlight to form ground-level ozone (or photochemical smog). The highest concentration of this pollutant is usually in the suburbs on hot and sunny spring and summer days (Nguyen et al. 2022; Riley et al. 2022).

Ozone concentration in 2019 was higher than in 2016. However, it is not possible to claim that this is a statistically reliable

Table 8 Ozone (O_3) concentration (µg/m^3) in the ambient air of Vilnius district: residential territory; recreation territory; areas close to intense transport streets

Residential territory							
Season/site	[O2]	[O3]	[O4]	[O8]	[O9]	[O13]	[O14]
Winter	50.4	47.5	55.4	35.8	26.4	51.8	19.4
Spring	68.6	67.8	98.4	63.1	58.8	76.5	79.2
Summer	45.4	61.6	44.1	29.5	26.4	58.7	51.8
Autumn	63.0	30.0	51.0	87.0	52.0	71.0	64.0
Recreation territory							
Season/site	[O7]		[O12]			[O16]	
Winter	24.8		35.0			22.5	
Spring	69.6		98.9			70.1	
Summer	43.2		47.0			41.4	
Autumn	60.0		44.0			72.0	
Areas close to intense transport streets							
Season/site	[O1]	[O5]	[O6]	[O10]	[O11]	[O15]	
Winter	37.5	52.6	21.0	61.3	54.7	46.0	
Spring	75.8	78.7	69.8	90.2	63.1	61.9	
Summer	38.9	45.6	31.0	49.5	63.4	45.4	
Autumn	65.0	30.0	43.0	101.0	55.0	51.0	
Annual limit value for the protection of human health	120.0						

increase; it is only an observed trend of increasing ozone concentration, the causes of which could be various changes in the intensity of transport, the ratio of concentrations of ozone precursors and meteorological conditions. The values of one of the VOC–benzene were found to be slightly above the detection limit and ranged from 0.4 to 1.5 μg/m^3 at all measurement sites. The highest values were set during the winter season (average of 1.1 μg/m^3) and were on average 1.4, 2.7 and 2.1 times lower in the following seasons. The average concentration of benzene in different seasons of the year was found to be equal to 0.5 μg/m^3 in autumn, 1.1 μg/m^3 in winter, 0.8 μg/m^3 in spring and 0.4 μg/m^3 in summer. The average concentration of benzene makes 0.7 μg/m^3 in all seasons.

Toluene concentration slightly differed at measurement sites 3, 5, 7 and 13 in the summer season and at measurement sites 4, 5, 7, 8 in autumn. The maximum value of 28.1 μg/m^3 was set at measurement site 13 in summer and 27.9 μg/m^3 at measurement site 5 in autumn. These sites are located close to larger transport hubs, and therefore a possible source of pollution is the vapour of unburned liquid fuel. These periods were dominated by a higher than normal temperature of 20–25 °C, which further intensified pollutant emissions. The range of the T/B ratio measured for the investigated area of Vilnius district fluctuated between 0.5 and 1.4 in 2016, which is a typical value of the rural and particularly of the urban area. Benzene concentration in Vilnius district varied from 0.5 to 3.2 μg/m^3, and the average value made 1.5 μg/m^3. The minimum value of benzene concentration was recorded to be 0.5 μg/m^3 in June 2016 (average value of the summer period made 0.6 μg/m^3).

A similar situation was observed investigating ethylbenzene and m-, p- and o-xylene. The concentrations of all four pollutants were largest in autumn and the highest one was established at measurement site 5 where the value of ethylbenzene was 36.3 μg/m^3, that of m- and p-xylenes was 37.5 μg/m^3 and that of o-xylenes was 12.0 μg/m^3. The determined average concentration of ethylbenzene in different seasons of the year equalled 4.8 μg/m^3 in autumn, 0.7 μg/m^3 in winter, 0.8 μg/m^3 in spring and 0.6 μg/m^3 in summer. Ethylbenzene concentration in Vilnius district varied from <0.5 to 0.6 μg/m^3, and the average value was equal to 0.4 μg/m^3. The minimum value of ethylbenzene concentration made <0.5 μg/m^3 and was recorded in June 2016 (average value of the summer period made 0.3 μg/m^3).

The average concentration of m- and p-xylenes was equal to 2.0 μg/m^3 in all seasons. The determined average concentration of m- and p-xylenes in different seasons of the year made 5.03 μg/m^3 in autumn, 0.8 μg/m^3 in winter, 0.9 μg/m^3 in spring and 1.2 μg/m^3 in summer. The average annual concentration of o-xylenes was 2.29 times lower than that of m- and p-xylenes, and the ratio varied from 1.44 to 2.91 times in individual seasons. Xylene concentration in Vilnius district fluctuated from 0.5 to 1.1 μg/m^3 in 2016, and the average value equalled 0.7 μg/m^3. The recorded minimum value of xylene concentration was equal to 0.5 μg/m^3 (average value of the summer period made 0.6 μg/m^3). The maximum value of xylene made 1.1 μg/m^3 (average value of the winter period reached 0.8 μg/m^3) and was detected in winter 2016. Xylene concentration in the ambient air of Vilnius district ranged from 0.5 to 1.0 μg/m^3 during winter and summer seasons.

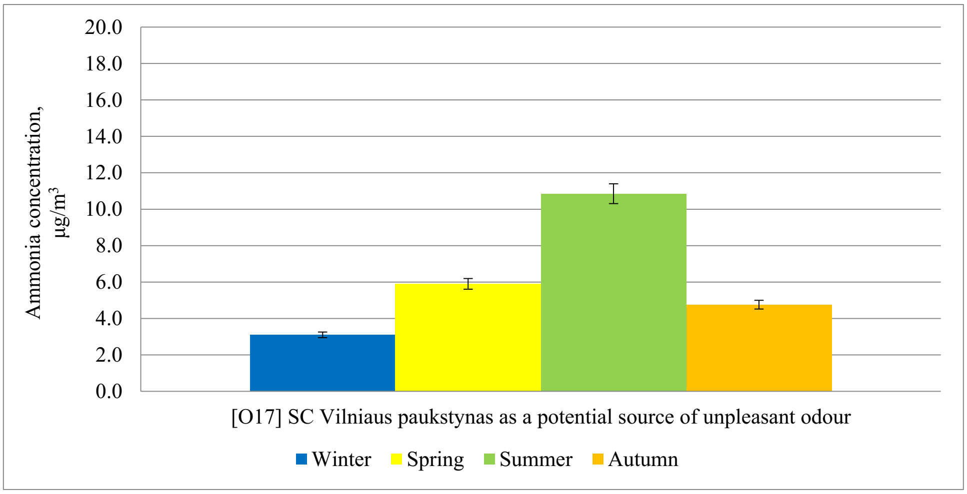
Particular attention is paid to the environmental monitoring of industrial enterprises located in the city or suburbs. The main objects of pollution with ammonia in Vilnius district include hen houses and technological buildings storing and processing chicken manure as well as handling organic and inorganic farm waste. The average daily ammonia concentration determined for each season is shown in Fig. 5.

The concentration of this pollutant in the air ranged from 3.1 to 10.9 μg/m^3 and was 3.69–12.9 times lower than the daily limit value (40.0 μg/m^3). Although the area of this economic activity is only 6 km away from the city limits; however, it is surrounded by the area of residential blocks, apartment and public buildings. Thus, the urbanization level of a district-type town is growing rapidly and is expected to develop in the future. Ammonia concentration varied steadily in different seasons of the year and was found to be higher in a warmer season (summer) thus reaching 10.9 μg/m^3. The average annual ammonia concentration is equal to 6.2 μg/m^3. At a temperature closer to 0 °C, emissions decrease on average by more than 2.5 times, and such pattern was identified during winter and spring seasons when temperature ranged between -2 and 2° C. The conducted research demonstrated the prevailing moderate wind speeds of 2.4–3.5 m/s. The research was carried out at the measurement sites just downwind of the pollution source at equal distances (750–850 m). It is assumed that the established concentration was highest and decreased steadily in other directions.

Pearson criterion was applied for the statistical analysis of the obtained research results when looking for a correlation between two pollutant values at the measurement sites. The coefficient of the received indicator shows the strength of the relationship between variations in two parameters, and the preliminary relationship is evaluated in line to the given scale: correlation is missing when the value of the correlation coefficient is equal to 0; correlation is very weak when the value of the correlation coefficient falls in the range of $(-0.2; 0)$ or $(0; 0.2)$; correlation is weak when parameters are equal to $(-0.4; -0.2)$ or $(0.2; 0.4)$; correlation is medium under parameters $(-0.7; -0.4)$ or $(0.4; 0.7)$; correlation is strong under parameters $(-0.9; -0.7)$ or $(0.7; 0.9)$; correlation is very strong under parameters $(-1.0; -0.9)$ or $(0.9; 1.0)$; linear relationship equals -1 or 1.

Among all analyzed cases, the strongest correlation is observed between the concentrations of PM_{10} and O_3 in spring under the Pearson coefficient equal to 0.64. A slightly lower correlation is noticed between the concentrations of CO and O_3 in summer, PM_{10} and NO_2 in spring, PM_{10} and CO in summer, PM_{10} and O_3 in winter and SO_2 and NO_2 in autumn under the Pearson coefficient equal to 0.51–0.57. A moderate to weak correlation was found in most cases, with the

Fig. 5 Daily concentration of ammonia in the ambient air of Vilnius district



concentrations of PM_{10} and SO_2 correlating the most (except for the summer season when correlation was very weak) under the Pearson coefficient fluctuating from − 0.402 to − 0.476 in all cases. The correlation between SO_2 and NO_2 was moderate in autumn only but weak during other seasons.

A very weak or weak correlation was discovered between the concentrations of PM_{10} and CO and CO and O_3, with the exception of comparing the results obtained during the summer season and the concentrations of SO_2 and CO. In the latter case, the exception is represented by the results obtained during the autumn season. The correlation between SO_2 and O_3 as well as between NO_2 and O_3 was very weak throughout all seasons with the weakest correlation seen between the concentrations of NO_2 and CO at the measurement sites.

In line to EU28 Gothenburg target, SO_2 limits make 12.5 and those of NO_2 38.8. Similar measurements were carried out in other Lithuanian cities, Kaunas and Vilnius. The findings showed that NO_2 concentration in the biggest cities of Lithuania ranged from 11.4 to 26.3 µg/m^3 in Kaunas and from 16.9 to 39.2 µg/m^3 in Vilnius (Ševervičienė and Paliulis 2011). Other researchers recorded the following results of NO_2 concentration in ambient air: Vietnam, 17.9–65.9 µg/m^3 (Hien et al. 2014); Kuwait, 12.8–29.0 µg/m^3 (Al-Awadhi 2014); Cuba, 4.8–21.4 µg/m^3 (Alejo et al. 2013); Canada, 0.3–1.52 µg/m^3 (Gibson et al. 2013); China, 1.1–45.0 µg/m^3 (Meng et al. 2010), the UK, 24.5–43.3 µg/m^3 (Stevenson et al. 2001); Turkey, 14.0–29.7 µg/m^3 (Akdemir 2014); Brazil, 49.0–63.0 µg/m^3 (da Silva et al. 2006); Pakistan, 82.8 µg/m^3 (Ahmad and Aziz 2013); and Spain, 18.1–29.4 µg/m^3 (Lozano García et al. 2010). Thus, NO_2 concentration in Lithuania is similar to that of other countries.

More researchers observed SO_2 concentration in ambient air and identified the following situation: Vietnam, 11.7–47.4 µg/m^3 (Hien et al. 2014); Kuwait, 6.5–15.4 µg/m^3 (Al-Awadhi 2014); Cuba, 2.1–10.5 µg/m^3 (Alejo et al. 2013); Canada, 0.6–0.6 µg/m^3 (Gibson et al. 2013); China, 1.8–176.3 µg/m^3 (Meng et al. 2010); Malaysia and Indonesia, 1.7 µg/m^3; East Asia, 5.0 µg/m^3; China and Nepal, 20.0 µg/m^3 (Carmichael et al. 2003); and Turkey, 8.0–21.0 µg/m^3 (Akdemir 2014; Pekey and Özaslan 2013). Hence, SO_2 concentration in Lithuania is lower than that of other countries. Conforming to the data provided by the Lithuanian Environmental Protection Agency, the concentrations of SO_2 and NO_2 in ambient air ranged up to 2.0 µg/m^3 and 15.0 µg/m^3, respectively.

Air pollution is expected to further decline in the coming years; however, only beyond 2030 slow progress is observed. At the end of 2013, the European Commission adopted a Clean Air Policy Package for Europe. The document proposed fully complying with the existing air quality legislation by 2030 and subsequently further improving air quality in Europe by 2030. As a part of this package, the Commission presented the amended NEC Directive recommending new emission reduction national level for 2020 and 2030. The amendment establishes stricter national emission reduction commitments for four main air pollutants, including sulfur compounds (mainly sulfur dioxide), nitrogen oxides, non-methane volatile organic compounds and ammonia. The limit values of the above introduced emissions apply to every country and to each pollutant from 2020 onwards. The fifth pollutant is fine particulate matter and is being regulated for the first time. The Protocol also sets emission reduction commitments for this pollutant.

Reducing emissions from energy facilities is one of the methods for mitigating climate change. To successfully achieve the goal, boilers are modernized by replacing combustion fuel with the one less polluting air (burnt fuel is most frequently replaced with gas) and installing air treatment equipment in energy facilities (usually for capturing particulate matter).

In order to develop infrastructure and improve transport in urban areas, a network of bypasses connecting the busiest roads from north-west to south-east and from south to north is being developed particularly fast. The employment of the circular communication model inevitably affects the above listed polluted areas thus posing additional engineering-technological challenges to avoid pollution problems. The installation of the main bypasses is often used in the artificially formed valleys (between two embankments). The resulting air pollutants remain at the road level and hardly spread over the embankments, whereas road construction is selected in the areas having the lowest potential for urbanization in the future but closer to the tertiary roads of minor importance to improve traffic.

Conclusions

- The average concentrations of CO, PM_{10} and NO_2 calculated in the areas close to intense transport streets during all investigated seasons were 0.5 mg/m^3, 18.3 µg/m^3 and 23.5 µg/m^3, respectively, which was more than 8% higher than the average level in the ambient air of Vilnius district.
- CO concentration in the ambient air of Vilnius district ranged from 0.03 to 3.0 mg/m^3 during the investigated period, O_3 concentration varied from 19.4 to 101.0 µg/m^3 and NH_3 concentration fluctuated from 3.1 to 10.9 µg/m^3.
- PM_{10} concentration in the ambient air of Vilnius district ranged from 1.4 to 53.4 µg/m^3 during the investigated period and exceeded the annual limit value (40.0 µg/m^3) set by European Union Council Directive 2008/50/EC in the areas close to intense transport streets.
- During the investigated period, the concentrations of BTEX (benzene, toluene, ethylbenzene, o-xylene and m, p-xylenes) in the ambient air of Vilnius district were higher than the limit of ethylbenzene more than 1.5 times and equalled 36.3 µg/m^3 at one of the measurement sites located close to intense transport streets. Other concentrations did not exceed the established limit values and the highest values were 1.5, 28.1, 8.0, 12.0 and 37.5 µg/m^3, respectively.
- During the investigated period, NO_2 concentration in the ambient air of Vilnius district ranged from 5.7 to 61.6 µg/m^3 and that of SO_2 fluctuated from 0.3 to 6.3 µg/m^3. Air pollution caused by the above mentioned pollutants did not exceed the limit values set by Gothenburg target and European Union Council Directive 2008/50/EC.
- The average concentration of the selected pollutants determined during the investigated seasons take a decreasing order: spring > winter > summer > autumn.

Author Contribution Conceptualization, A.C. and D.P.; methodology, A.C. and D.P.; software, A.C. and D.P.; validation, A.C. and D.P.; formal analysis, A.C.; investigation, A.C., D.P. and J.B.; data curation, A.C., D.P. and J.B.; writing—original draft preparation, A.C., D.P. and J.B.; writing—review and editing, A.C.; visualization, A.C.; supervision, T.J.; project administration, A.C.; funding acquisition, T.J. All authors have read and agreed to the published version of the manuscript.

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Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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