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ORIGINAL PAPER

ANALYSIS OF CHANGES IN NITROGEN DIOXIDE CONCENTRATION IN SELECTED EUROPEAN CITIES IN THE FIRST COVID-19 WAVE*

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Abstract

Of the nitrogen oxides, NO_2 has the greatest impact on humans. The areas with its highest concentrations within the EU are these most populated and industrialised ones. Excessive nitrogen dioxide concentrations are responsible for around 75,000 premature deaths of EU residents each year; in Poland, this value reaches almost 1,900. Since 2017, there have been new possibilities to measure NO_2 concentration, made as part of the Copernicus Sentinels-5P Programme. Hence, it is purposeful to analyse changes in nitrogen dioxide emissions in the most important Polish cities against the EU in spring and summer 2020. The basis for the analysis was satellite data collected during the Copernicus Sentinels-5P Programme. In 2020, there were huge changes in NO_2 concentration, which were the consequences of the implementation of restrictive safety measures relating to the COVID-19 pandemic: a significant reduction in road traffic and the closure or limiting of production in many industrial plants. It was found that, as a result of lockdown, nitrogen dioxide concentrations in Poland's largest cities fell to a much lesser degree than in cities of similar size in southern or western Europe. The analyses indicated that data obtained from the Copernicus Sentinel-5P satellite will play a key role in monitoring changes in nitrogen dioxide concentration throughout the EU. Ground-based observations of nitrogen dioxide concentrations, which have dominated until recently, will remain only of comparative importance in the assessment and analysis of the compound concentration.

Keywords: NO_2, Copernicus Sentinel-5P, No_x, nitrogen dioxide emissions, Polish cities.

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INTRODUCTION

Of the nitrogen oxides, NO_2 has the greatest impact on humans. It causes respiratory problems, cardiovascular diseases and eye irritation. Nitrogen oxides are also a catalyst for the formation of carcinogenic compounds which leach into food.

In the EU, the areas with its highest concentrations are these most populated and industrialised ones.

Treatment of diseases resulting from high levels of NO_2 costs hundreds of billions of euros. Excessive nitrogen dioxide concentrations are responsible for approximately 75,000 premature deaths of EU residents each year. In Poland, this is about 1,900 people (EEA 2020).

NO_2 concentrations exceeding 130 μmol m^{-3} significantly increase mortality among Corvid-19 patients (Filippini et al. 2020).

From January to March 2020, 78% of COVID-19 deaths occurred in five regions of Germany, which have the highest nitrogen dioxide concentrations among the sixty-six regions analysed in Germany, France, Italy and Spain (Ogen 2020).

Based on epidemiological data, it was established that by reducing air pollution levels, about 19% of COVID-19-related deaths in Europe could be avoided. For Poland, the figure was 28% (Pozzer et al. 2020).

NO_2 concentrations are influenced by both natural and anthropogenic factors. Other nitrogen oxides emitted from exhaust pipes of cars and chimneys of some enterprises and households are converted into this compound. The effect of meteorology on the observed changes in NO_2 concentrations is very important and should not be ignored when analysing air pollution. For traffic routes, wind direction and traffic volume are decisive. Secondary factors are temperature and relative air humidity (Kamińska, Turek 2020). In the case of fossil fuel combustion, nitrogen oxide emissions are affected by the fuel quality, the combustion temperature, and the combustion process used. In poorly ventilated rooms, NO_2 air pollution levels are often much higher than those outside (Al-Sultan et al. 2019). Construction projects slightly increase the NO_2 concentration, i.e. by a maximum of about 7% in the construction area (Mucha, Żeliński 2019).

Since 1 January 2010, the maximum hourly and annual average concentrations in the EU are 200 and 40 μg m^{-3}, respectively (Directive of 21 May 2008; *Nitrogen dioxide – Annual limit* 2014; EUR-Lex - 32015L1480 - EN - EUR-Lex (europa.eu) EUR-Lex - 32015L1480R(01) - EN - EUR-Lex (europa.eu)).

As a result of the EU authorities' policies between 2009 and 2018, annual average NO_2 concentrations decreased by 18%. Despite this, hundreds of European cities were still exceeding emission limits in 2018. These were not only very large centres like Paris, London or Berlin (air-quality-traffic-measures-could-effectively-reduce-no2-concentrations-40-europe-s-cities

27 November 2019). In Germany alone, these were then 57 cities (2018-data-on-air-quality-57-cities-exceed-the-no2).

For example, in 2018, the European Commission took Germany, France and the UK to the Court of Justice of the European Union for exceeding the EU NO_2 standards (Air quality 2018).

Monitoring air pollution by NO_2 is therefore important for public health (Machowicz 2021).

Since 2017, the importance of ground stations and mobile devices for measuring NO_2 concentrations has been significantly reduced as a result of launching the Copernicus Sentinels-5P Programme. In the EU, directives are being prepared to oblige the corresponding authorities of the European Commission to use satellite data. These will be translated into reality. In 2020, satellite data were used to monitor changes in NO_2 quality triggered by the implementation of restrictive safety measures relating to the COVID-19 pandemic.

The Copernicus Sentinels-5P Programme includes, inter alia, the development of Copernicus Sentinel satellites and the provision of data flows for the EU Copernicus environmental programme. Continuous atmospheric measurements carried out by the mission are used, for instance, for air quality monitoring, continuous observation of changes in the spatial distribution of pollutants and climate changes. The programme is supervised by the European Commission.

For more accurate imaging of air pollution, the satellite is equipped with a state-of-the-art instrument with dedicated applications for the identification of atmospheric gases – the TROPOspheric Monitoring Instrument. Its performance in terms of sensitivity, spectral, spatial and temporal resolution provides very high quality observations. It takes measurements every second over an area of 2600 km at 7 km 7 km resolution (Geffen et al. 2020).

MATERIAL AND METHODS

This article is based on satellite data collected during the Copernicus Sentinels-5P Programme. Due to deficiencies in available data, in several cases, results from ground-based measuring stations were used for comparison (e.g. for Warsaw). As for Poland, the focus was on cities with a population of over 250,000 (Warsaw, Kraków, Łódź, Wrocław, Poznań, Gdańsk, Szczecin, Bydgoszcz, Lublin, Białystok, Katowice).To show the scale of changes in NO_2 concentrations over time in the first Covid-19 wave, selected data for 2018 and 2019 were included in this study for comparison.

Sentiel-5P maps presented in publications, especially for comparing changes in emission trends, very often show concentrations over a monthly period and have a 15% error tolerance, which results from weather variability. The greatest limitations of the Sentinel-5P data are the impact of cloud cover on data quality and the small number of daily observations of the same area. In many countries, atmospheric conditions change overnight, which has a large effect on the NO2 dispersion degree and the readings. In order to eliminate measurement anomalies, it is necessary to analyse data over a longer period of time. This is the reason for frequent analyses of air quality changes in monthly or quarterly cycles (*Coronavirus lockdown leading* 2020). Averaging the data over longer periods of time allows one to see trends and clearer changes in concentrations resulting from human activity.

Satellite measurements are the average result of NO_2 content measurements in the whole air column. The level of pollution, which is from a few to several metres above the ground, requires comparison with data from ground measurement stations. Ground-based stations record pollution with greater accuracy, but collect information only from measurement points (Figure1).

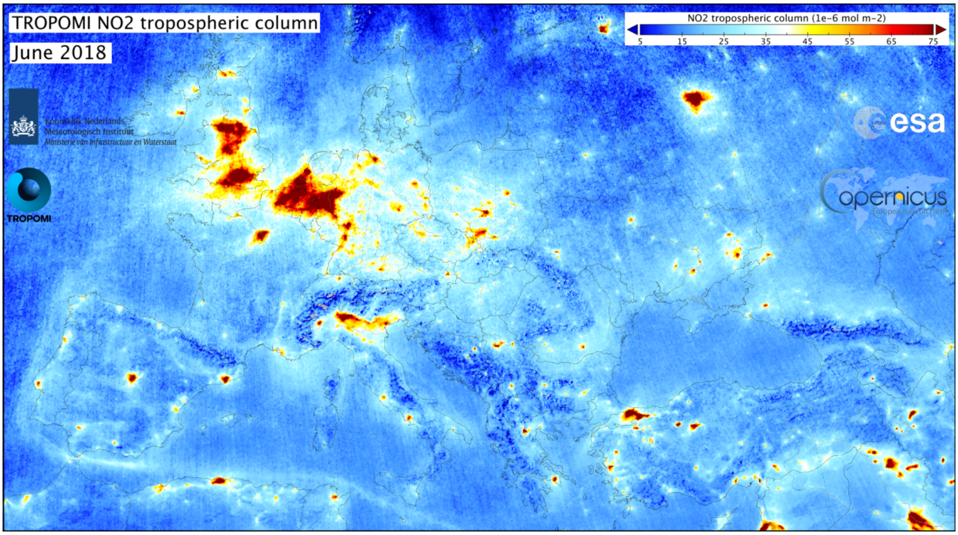

Fig. 1. June 2018 monthly nitrogen dioxide concentrations across Europe – Sentinel-5P satellite image (http://www.tropomi.eu)

So far, studies using satellite data collected under the Copernicus programme have focused either on a global scale (Bauwens et al. 2020) or on a part of a country (Northern Italy) – Filippini et al. (2020) or on an earlier period and a specific country, e.g. France (Omrani et al. 2020). Many valuable insights into the discussed topic on a European scale can be found in the article by Vîrghileanu, Savulescu, Mihai, Nistor, Dobre (2020). With the exception of the Finnish capital (Ialongo et al. 2020), there are no studies comparing satellite data with those obtained through ground measurement stations. There are no analyses of ecologists' point of view on NO_2 satellite data, either.

RESULTS AND DISCUSSION

Figure 2 shows the results of measurements from ground-based stations in different EU countries in 2018. Colour-categorised points correspond to values above the annual EU limit value (40 μg m^{-3}). The map includes stations with more than 75% valid data (Figure 2).

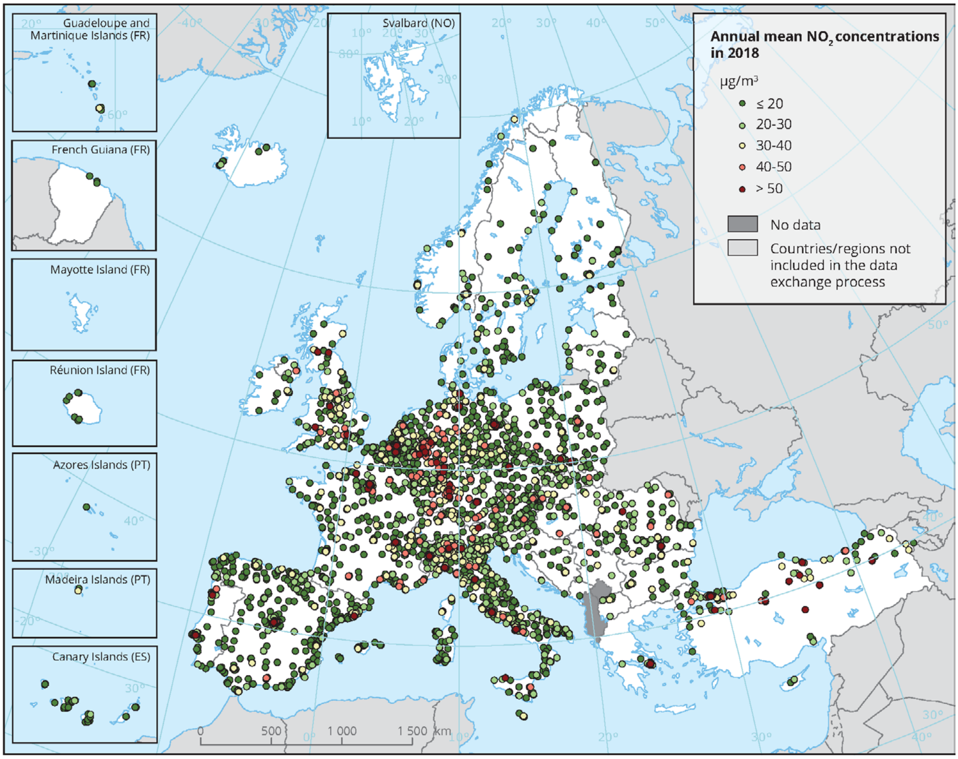

Fig. 2. Annual mean NO_2 concentrations recorded from ground-based measurement stations in 2018. (annual-mean-no2-concentrations-in-3, 2020)

The concentration levels in the analysed cities vary. As shown in Figure 2, concentrations in Katowice and Wrocław are similar to those in Warsaw and Kraków.

Environmental organisations present Poland as a highly polluted country, lagging behind in the implementation and respect of laws limiting air pollution by NO_2 (e.g. Programme 2018). Analysis of satellite data, which is confirmed by ground-based data and forecasts (e.g. NaszePowietrze 2021), indicate that this allegation is only partly correct.

It is true that in 2019, the air over Poland was polluted with 188.1 thousand tonnes of NO2 only from particularly onerous plants themselves – mainly in the Łódzkie, Śląskie and Mazowieckie voivodeships (*Statistical*

Yearbook of the Regions – Poland 2020). However, this was not much compared to the volume of nitrogen oxide emissions in the largest cities in the western and southern parts of the EU (ESA/Copernicus/Sentinel-5P 2018).

According to the data of the Chief Inspectorate for Air, in 2018 in Poland, Kraków, Katowice and Warsaw mainly should be classified the zones exceeding the permissible parameters of NO_2 (GIOS 2019).

It was indicated that the greatest traffic congestion was in 2019 in Rome, where people spent an average of 166 hours in traffic jams. This was followed by Paris (165 h) and Dublin (154 h) (https://inrix.com/scorecard 2019). According to other data (TomTom Traffic Index), a significant proportion of the most congested cities in the European Union is in Poland. They are: Kraków, Poznań, Waraw, Wrocław, Bydgoszcz, Gdańsk, Gdynia, Sopot, Szczecin, Lublin, Białystok, Bielsko-Biała, Katowice, and Łódź.

Satellite data (Figures 1, 3) show that cities such as Paris, Brussels, Amsterdam and highly urbanised regions such as the Ruhr and the Po Valley have some of the highest NO_2 emissions in the EU.

Lockdowns in densely populated and industrialised areas of Europe between March and April 2020 led to significant decreases in NO_2 levels. For example, Madrid, Milan and Rome saw a decrease of around 45%

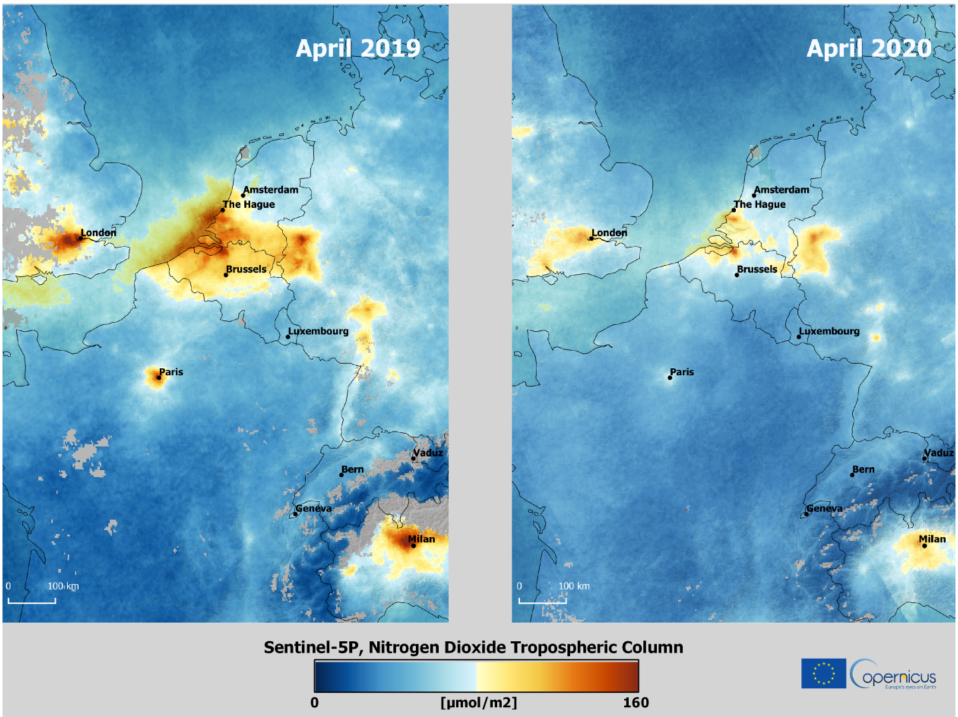

Fig. 3. Changes in NO_2 concentrations in the Benelux and adjacent areas in April 2019 and 2020 (https://www.copernicus.eu/en/media/image-day-gallery/nitrogen-dioxide-central-europe)

between 13 March and 13 April 2020, and Paris a decrease of 54% (Air pollution remains, 2020). This was particularly noticeable in regions such as the Ruhr in Germany and the Po Valley in northern Italy (Figure 4) and resulted from significant reductions in traffic, as well as in the industrial and energy sectors.

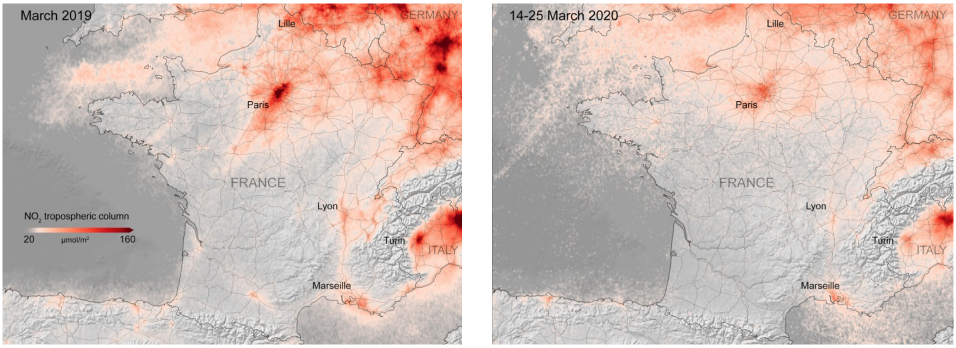

Fig. 4. Nitrogen dioxide concentration in France in March 2019 and 2020 (http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe)

The satellite data (Figure 5) indirectly shows that, in the period from 15 March to 30 April 2020, EU cities with more than 500,000 inhabitants with the highest reduction in average daily NO_2 concentration were located in Spain (Barcelona – 59%, Madrid – 47%) and Italy (Milan – 54%, Turin – 47%, Rome and Genoa – 39%, Naples – 36%). These were followed by France (Marseille – 49%, Lyon – 34%, Paris – 30%), Germany (Munich – 37%, Bremen – 36%, Berlin – 33%, Hamburg – 28%, Frankfurt – 27%), the UK (Bradford – 36%, Manchester – 31%, Glasgow – 29%, London – 26%) and Belgium (Antwerp – 29%).

The satellite images below show the average NO_2 concentrations between 13 March and 13 April 2020 compared to the average concentrations noted in March and April 2019 (Figure 6). The satellite data presented in this study indicate that in some large cities, pollution levels decreased by up to 45-54% in 2020 compared to the same period in 2019.

The measurement results showed that the highest decreases of more than 50% were recorded in the first lockdown phase in Spain, Italy and France (Figure 5) between March and May 2020.

When comparing the data in Figures 3, 4, 5, 6, it is worth noting their coincidence. Using Paris as an example, when comparing the periods in 2019 and 2020, it can be seen that average daily concentration fell by 30% from 15 March to 30 April. The situation is similar in other cities such as Marseille, Nice and Lyon.

Remarkably, several cities recorded an increase in average daily concentration of around 10-13%, for example Gothenburg (Sweden), Braga (Portugal),

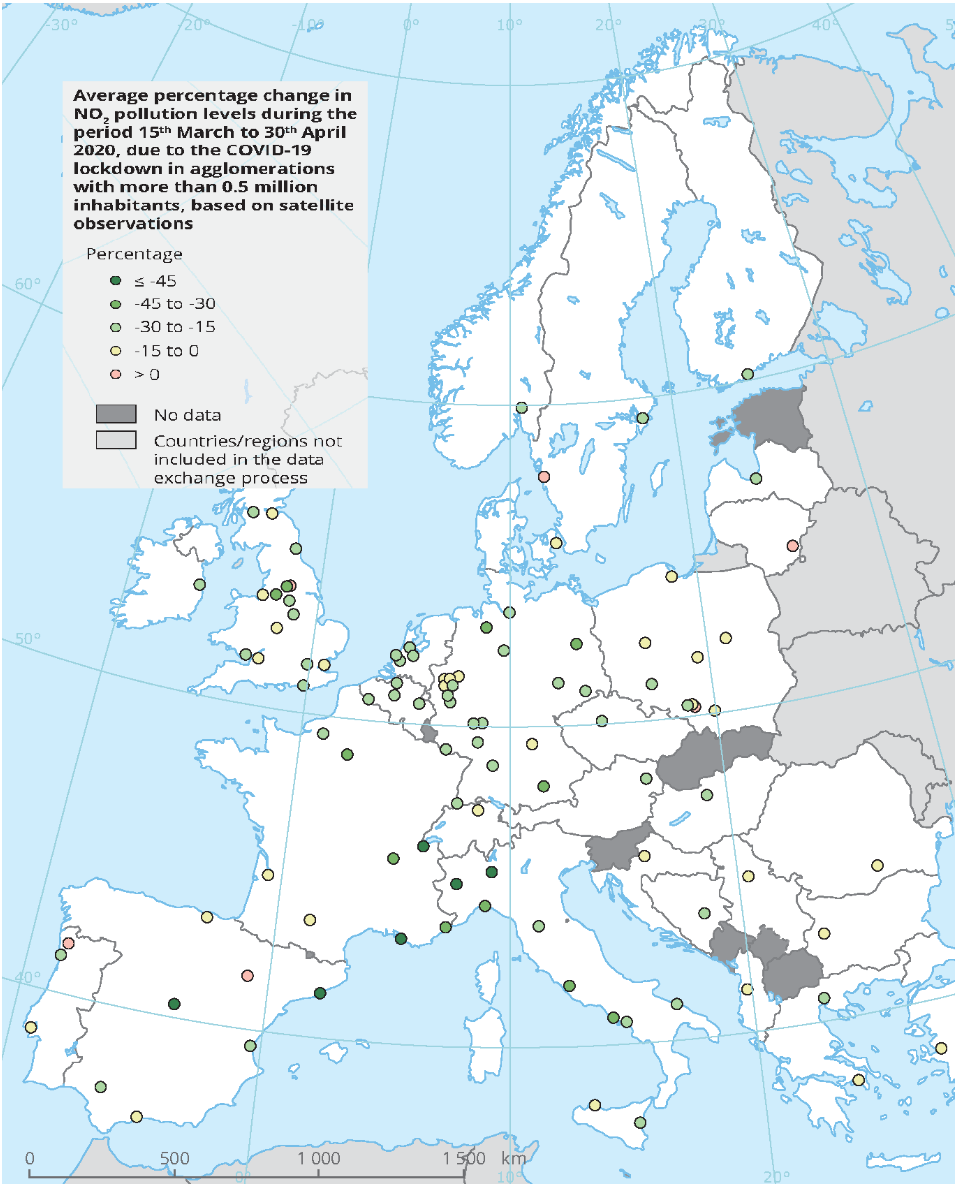

Fig. 5. Average percentage change in NO_2 pollution levels across the EU between 15 March and 30 April 2020 in agglomerations with more than 0.5 million inhabitants, based on satellite observations (eea 2020)

Vilnius (Lithuania) and Katowice (EEA 2020). This was due to differences in national pandemic control restrictions. In Italy and Spain, for instance, a very restrictive lockdown was introduced during that period, which translated into high emission drops. On the other hand, in Sweden, the COVID-19

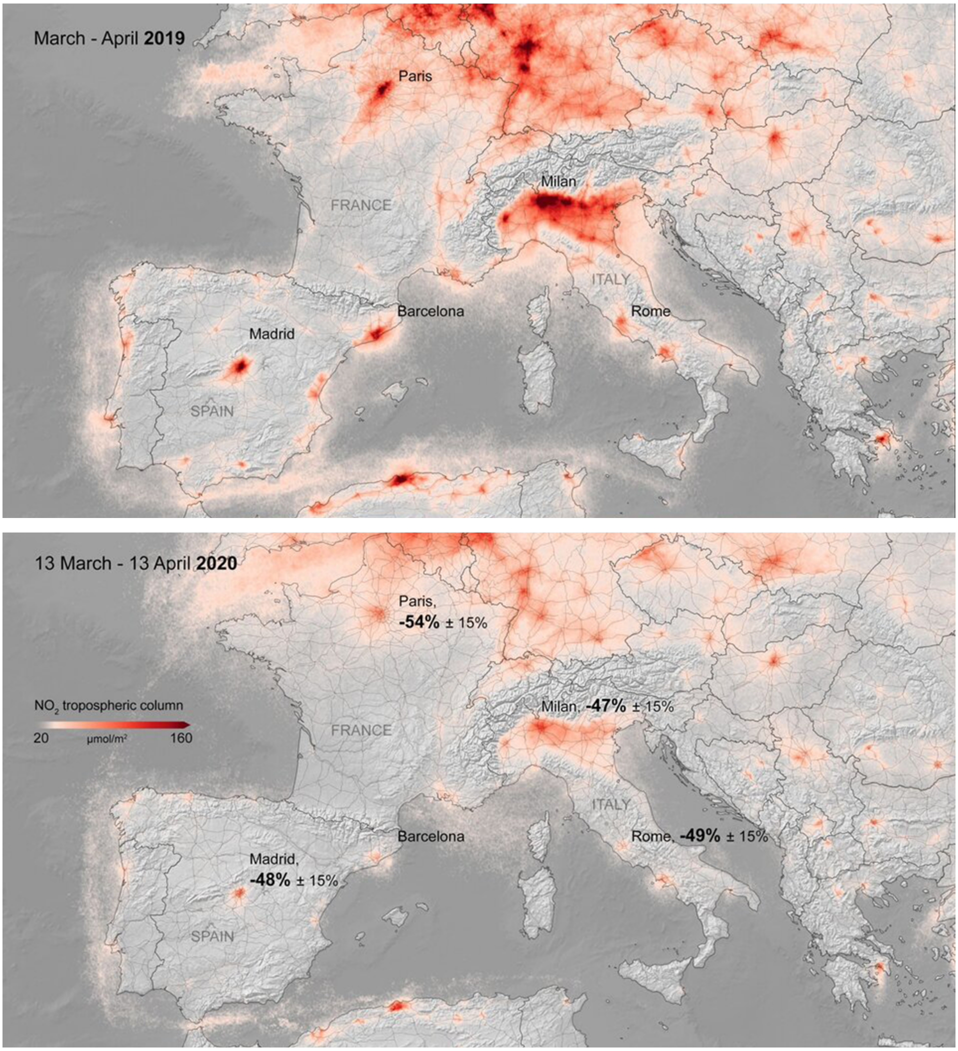

Fig. 6. Concentration of nitrogen dioxide emissions in March-April 2019 and 2020 (http://www.esa.int/ESA_Multimedia/Images/2020/04/Nitrogen_dioxide_concentrations_over_Europe)

restrictions were practically unnoticeable, the wearing of protective masks was not even recommended and no lockdown was introduced. This resulted in an increase in NO_2 emissions. Elevated concentrations in this area were due to residents' fear of close contacts with others during the pandemic and the associated increased use of vehicles emitting exhaust.

In contrast, increased NO_2 concentrations in the area of Zurich, Gijon (Spain) and by the sea at the mouth of the Seine were not solely caused by changes in weather, including wind direction. Gijon and La Havre are industrial centres. In general, the pandemic obviously had a very negative impact on this part of the economy (e.g. NICOLAA et al. 2020). However, there were parts of the EU where industrial production in some branches in spring and summer 2020 increased. In turn, there were regions where higher concentrations were due to other reasons, e.g. the north-eastern Lublin region (Figure 7).

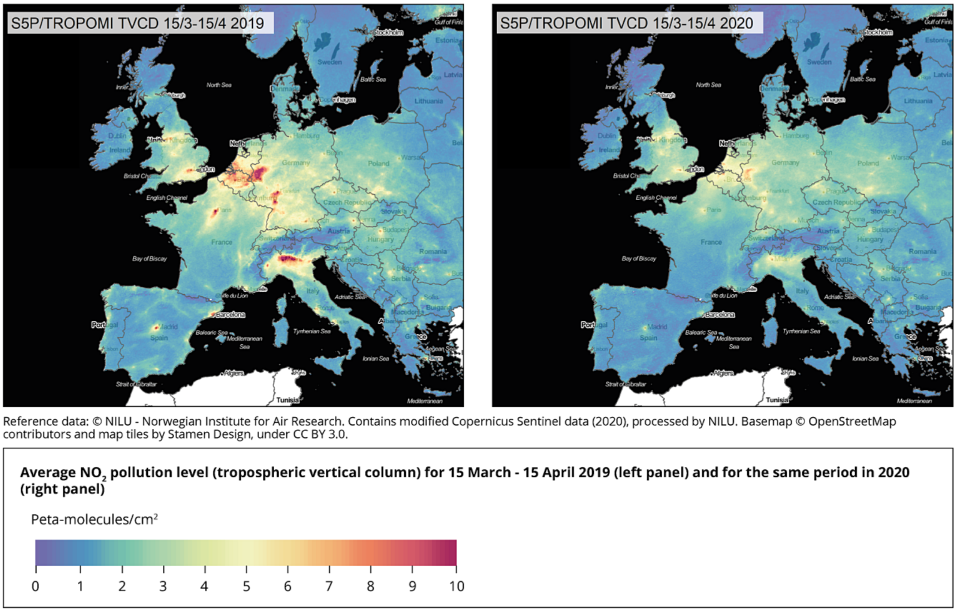

Fig. 7. Average NO_2 pollution level based on Sentinel-5P for the period of: 15.03. – 15.04. of 2019 and 2020 (https://www.eea.europa.eu/data-and-maps/figures/average-no2-pollution-level-tropospheric).

A comparison of the recorded readings from 2020 and 2019 showed that in March 2020, average daily nitrogen dioxide concentrations in Warsaw fell by almost six times, from 147 to 26.1 µg m^{-3} (Smoglab 2020). The graph (Figure 8) shows that nitrogen oxide emissions started to decrease significantly from 10 March 2020.

As can be seen in Figures 5 and 7, in some of the analysed Polish cities, the decrease in the average daily pollution in Gdańsk, Warsaw, Poznań and Kraków accounted for a maximum of over ten percent.

The analysis of these maps revealed that there were also areas where there was virtually no change, such as southern Denmark or Zagreb in Croatia. The reason for this was the generally low level of emissions in these areas.

The graphs below show the average 14-day NO_2 concentrations (Y axis) in Milan, Madrid, Paris, Berlin, and Budapest from March to September (X axis). The top plot shows concentrations in March-September 2019 com-

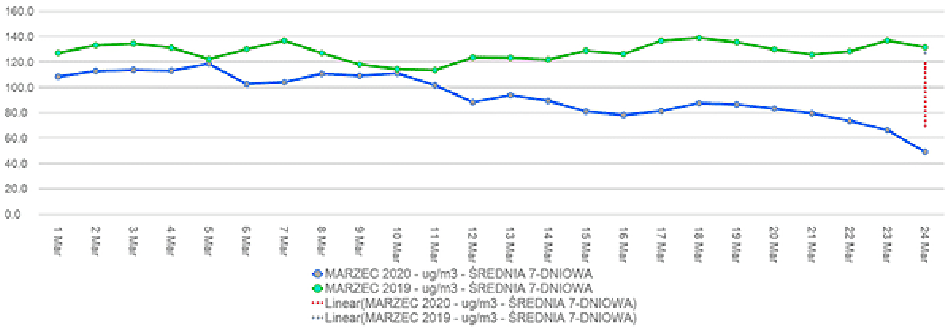

Fig. 8. Comparison of average daily nitrogen dioxide concentrations in Warsaw in March 2019 and 2020 in μg m^{-3} (Smoglab 2020)

pared to 2020 using data from Sentinel-5P, while the bottom plot allows comparison of data collected from ground-based stations, at the location where the pollution was observed (Figure 9).

The shades of grey in the background of the graphs indicate the lockdown periods in 2020 for each city, moving progressively from the most (dark grey) to less (light grey) restrictive. The percentages in red indicate the decrease in NO_2 emissions in 2020 compared to 2019 for the same monthly cycle.

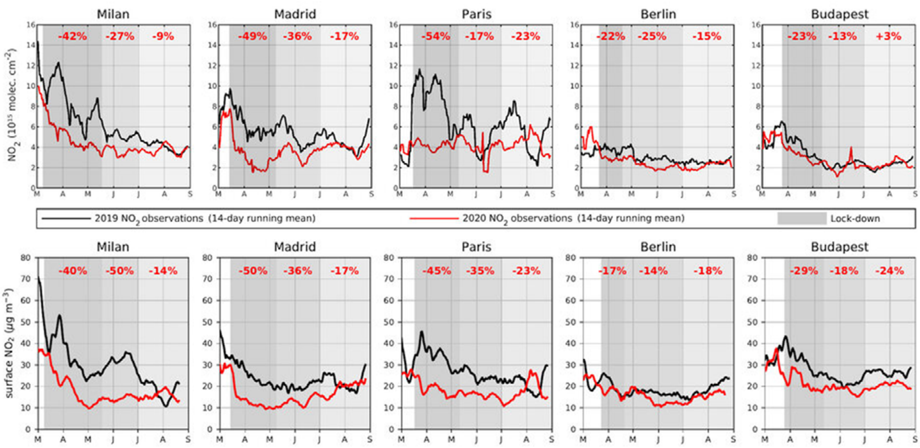

Fig. 9. Comparison of nitrogen dioxide monitoring results in Milan, Paris, Madrid, Berlin, and Budapest: March-September 2019 and 2020 (https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P)

As can be seen from the figure above, the quarantine measures implemented in Berlin led to a decrease in emissions of around 20% with slight fluctuations until August 2020. A similar situation was observed for Budapest.

Figure 9 shows that, despite the passage of time and the relaxation of restrictions, average daily NO_2 concentrations returned almost to 2019 levels in the period from August to September 2020, except in large cities. The average daily NO_2 concentration in autumn 2020 was still 10% to 20% lower than before the COVID-19 outbreak. This was due to a significant reduction in the traffic of diesel engine-driven vehicles, partially caused by compliance with pandemic-related restrictions.

A comparison of measurements from ground-based stations and satellite readings clearly showed that the ground and satellite measurements diverge. However, this was not due to errors in measurements or or analysis of the data set, but to factors changing the concentration at altitudes from a few metres to about 12 km above the ground, i.e. the upper troposphere. Over such a distance, significant gas diffusion can occur resulting in a decreased average daily NO_2 concentration over the studied area.

Satellite data indicated a dominant role of mountain ranges and main air currents on migration and dispersion of pollutants. Mainly for this reason, a statistically significant part of emitted nitrogen oxides, after transformation into NO_2, ends up outside the EU region or country where it originated (Richmond-Bryant et al. 2018). In 2020, NO_2 emissions in the EU affected the average NO_2 concentration e.g. in Morocco (Sekmoudi et al. 2020).

Pollution in central and northern European areas is, among other things, the result of major air masses following the west-to-east direction. Another example is the Lombardy region, where geographical conditions make mountain ranges and unfavourable winds limit the dispersion of gases and favour increases in pollutant concentrations (Vîrghileanu et al. 2020).

However, there is no complete information yet on the reduction in the number of public transport user in the 11 Polish cities analysed. In 2019, buses, trams and trolleybuses were used 3864.9 million times in Poland (*Statistical Yearbook of the Republic of Poland* 2020).

The number of passenger journeys in Poland’s large cities in 2020 is likely to have fallen by 30% (Zachowania transportowe 2021). Such estimates are confirmed by exceptionally large drops in passenger volumes in Italy and Spain, for example, in and around Barcelona where passenger numbers fell by an average of 90% (public-transport-coronavirus-barcelona 2020).

There are also other reasons for the differences between the 11 cities analysed and their counterparts in Western Europe. In the largest cities in Poland, the population level is lower compared to similar-sized cities in Western Europe (Population_statistics_at_regional_level). It has been demonstrated, using the example of several Polish voivodeships, that air pollution decreases with a lower population density (Stelągowski 2019).

CONCLUSIONS

In 2020, huge changes in average daily NO_2 concentration were observed, triggered by the consequences of the implementation of restrictive safety measures relating to the COVID-19 pandemic: a significant reduction in road traffic and the closure or limiting of production in many industrial plants. Analyses of studies showed persistently low levels of nitrogen dioxide concentrations over almost the entire EU, coinciding with the measures taken and implemented by national authorities to contain the spread of the coronavirus.

Observations from the Copernicus Sentinel-5P satellite will now play a key role in monitoring changes in not only No_x emissions, but all greenhouse gases across the EU. Ground-based observations of nitrogen dioxide concentrations will remain only of comparative importance in the assessment and analysis of the compound concentration. This is indicated, inter alia, by the quality of the satellite maps included herein, which makes it possible to read average concentrations (and subsequently to compare them with data from ground-based stations).

Data must be analysed on a monthly basis in order to better assess the impact of human activity.

Another advantage is the possibility to observe factors affecting the change in average daily concentration both near the ground and in the upper troposphere. Not all of the nitrogen oxides emitted reach only the studied area, which is caused by variable weather conditions.

During the strict restrictions in March and April 2020, the impact of lockdowns on NO_2 emission reductions in the 11 largest Polish cities took a less drastic form than in similar-sized cities in Western Europe. Annual mean readings of nitrogen dioxide concentrations in cities with more than 500,000 inhabitants in Western Europe were still clearly higher than the mean of both their Polish counterparts and the analysed 11 largest cities in this country.

REFERENCES

Air pollution remains 2020 – Air_pollution_remains_low_as_Europeans_stay_at_home. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/

Air quality: Commission takes action to protect citizens from air pollution (europa.eu)

Al-Sultan A.A., Jumaah G.F., Al-Ani F.H. 2019. *Evaluation of the dispersion of nitrogen dioxide and carbon monoxide in the indoor café – case study*. J Ecol Engin, 20(4): 256-261.

Bauwens M., Compernolle S., Stavrakou T., Müller J., Gent van J., Eskes H., Levelt P.F., Der van A. R., Veefkind J.P., Vlietinck J., Yu H., Zehner C. 2020, *Impact of coronavirus outbreak on NO_2 pollution assessed using TROPOMI and OMI observations*. Geophys Res Lett, 47. DOI: 10.1029/2020GL087978

CEM, 2021. *Transport behavior of inhabitants in large cities*, https://polskialarmsmogowy.pl/wp-content/uploads/2021/06/Raport_zachowaniatransportowe_miasta_skrot1.pdf. (in Polish)

Coronavirus lockdown leading 2020 -Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe. https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/

Directive of 21 May 2008 – *https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32008L0050*

European Environment Agency (EEA) 2020. *Air quality in Europe – 2020 report*. https://www.eea.europa.eu/publications/air-quality-in-europe-2020-report

ESA/Copernicus/Sentinel - https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Nitrogen_dioxide_pollution_mapped?fbclid=IwAR0kY0kuSpQXzWtxe08hrjw15dUa3f1_2By1PbLzv4DKUsWpMgaKhqzykeQ

EUR-Lex - 32015L1480 - EN - EUR-Lex (europa.eu).

EUR-Lex - 32015L1480R(01) - EN - EUR-Lex (europa.eu).

Filippini T., Rothman K.J., Goffi A., Ferrari F., Maffeis G., Orsini N., Vinceti M. 2020. *Satellite-detected tropospheric nitrogen dioxide and spread of SARS-CoV-2 infection in Northern Italy*. Sci Total Environ, 739, 140278. DOI: 10.1016/j.scitotenv.2020.140278

Geffen van J., Boersma K.F., Eskes H., Sneep M., Ter Linden M., Zara M., Veefkind J.P. 2020. *S5P TROPOMI NO_2 slant column retrieval: Method, stability, uncertainties and comparisons with OMI*. Atmos Meas Tech, 13: 1315-1335. DOI: 10.5194/amt-13-1315-2020

GIOS 2019. https://powietrze.gios.gov.pl/pjp/documents/download/104548

http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Coronavirus_lockdown_leading_to_drop_in_pollution_across_Europe

http://www.esa.int/ESA_Multimedia/Images/2020/04/Nitrogen_dioxide_concentrations_over_Europe

http://www.tropomi.eu

https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Population_statistics_at_regional_level/pl&oldid=152642

https://ec.europa.eu/jrc/en/news/air-quality-traffic-measures-could-effectively-reduce-no2-concentrations-40-europe-s-cities, 27.11.2019

https://inrix.com/scorecard

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-5p

https://www.copernicus.eu/en/media/image-day-gallery/nitrogen-dioxide-central-europe

https://www.eea.europa.eu/data-and-maps/figures/annual-mean-no2-concentrations-in-3

https://www.eea.europa.eu/data-and-maps/figures/average-no2-pollution-level-tropospheric

https://www.eea.europa.eu/data-and-maps/figures/average-percentage-change-in-no2

https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P

https://www.trainsfare.eu/public-transport-coronavirus-barcelona/

https://www.umweltbundesamt.de/en/press/pressinformation/2018-data-on-air-quality-57-cities-exceed-the-no2

Ialongo I., Virta H., Eskes H., Hovila J., Douros J. 2020. *Comparison of TROPOMI/Sentinel-5 precursor NO_2 observations with ground-based measurements in Helsinki*. Atmos Meas Tech, 13(1): 205-218. DOI: 10.5194/amt-13-205-2020

Kamińska J. A., Turek T. 2020. *Explicit and implicit description of the factors impact on the NO_2 concentration in the traffic corridor*. Arch Environ Prot, 46(1): 93-99.

Mucha W., Żeliński J. 2019. *The impact of construction works conducted on the route DTŚ on a local air quality evaluated with the use of NO_2 measurements*, Archi Civil Engineer Environ, 12(1): 145-153.

Machowicz K. 2020. *Policy of law-creation in the field of air quality improvement in Poland and the interests of enterprises*. Prz Zach, 377(4): 167-176. (in Polish)

NaszePowietrze (uni.wroc.pl)

Nicolaa M., Alsafib Z., Sohrabic C., Kerwand A., Al-Jabird A., Iosifidisc C., Aghae M., Agha R. 2020, *The socio-economic implications of the coronavirus pandemic (COVID-19) a review*. Int J Surg, 78: 185-193.

Nitrogen dioxide - Annual limit 2014. https://www.eea.europa.eu/data-and-maps/figures/nitrogen-dioxide-annual-limit-values-for-the-protection-of-human-health

Ogen T. 2020. *Assessing nitrogen dioxide (NO 2) levels as a contributing factor to coronavirus (COVID-19) fatality*. Sci Total Environ, 726: 138605. DOI: 10.1016/j.scitotenv.2020.138605

Omrani H., Omrani, B., Parmentier B., Helbich M. 2020. *Spatio-temporal data on the air pollutant nitrogen dioxide derived from Sentinel satellite for France*. Data in Brief, 7(28): 105089. DOI: 10.1016/j.dib.2019.105089

Pozzer A., Dominici F., Haines A., Witt C., Munzel T., Lelieveld J. 2020. *Regional and global contributions of air pollution to risk of death from COVID-19.* Cardiovasc Res, 116: 2247-2253. DOI: 10.1093/cvr/cvaa288

Program 2018 - program_2018-calosc-rozkład-2.pdf (partiazieloni.pl).

Richmond-Bryant J., Snyder M.G., Owen R.C., Kimbrough S. 2018. *Factors associated with NO_2 and NO_X concentration gradients near a highway*, Atmos Environ, 174: 214-226.

Sekmoudi I., Khomsi K., Faieq S., Idrissi L. 2020. *Covid-19 lockdown improves air quality in Morocco*. arXiv, arXiv:2007.05417

Smoglab 2020. https://smoglab.pl/koronawirus-mniejszy-ruch-i-mniejsze-zanieczyszczenie-w--warszawie-smog-jednak-nie-znika/.

Statistical Yearbook of the Regions – Poland. GUS, 2020. (in Polish)

Statistical Yearbook of the Republic of Poland. GUS 2020. (in Polish)

Stelęgowski A. 2019. *Correlations between air pollutant concentrations in selected urban and rural areas in Poland*. Acta Innov, 31: 14-22. DOI: 10.32933/ActaInnovations.31.2

Vîrghileanu M., Savulescu I., Mihai B. A., Nistor C., Dobre R. 2020. *Nitrogen dioxide (NO_2) pollution monitoring with Sentinel-5P Satellite imagery over Europe during the coronavirus pandemic outbreak*. Remote Sensing, 12(21): 3575. DOI: 10.3390/rs12213575