Variations in the tropospheric concentration of NO₂ in the central west of Brazil, MS, and their relationship with the COVID-19

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Abstract

COVID-19 (coronavirus disease 2019) started in late 2019 in Wuhan, China. Subsequently, the disease was disseminated in several cities around the world, where measures were taken to control the spread of the virus through the adoption of quarantine (social isolation and closure of commercial sectors). This article analyzed the environmental impact of the COVID-19 outbreak in the state of Mato Grosso do Sul, Brazil, regarding the variations of nitrogen dioxide (NO₂) in the atmosphere. NO₂ data from the AURA satellite, in the period before the beginning of the epidemic (2005–2019) and during the adoption of the preventive and control measures of COVID-19 in 2020, were acquired and compared. The results obtained from the analysis showed that the blockade from COVID-19, beginning in March 2020, improved air quality in the short term, but as soon as coal consumption in power plants and refineries returned to normal levels (since June 2020), due to the resumption of works, the pollution levels returned to the level of the previous years of 2020. NO₂ levels showed a significant decrease, since they were mainly associated with the decrease in economic growth and transport restrictions that led to a change in energy consumption and a reduction in emissions. This study can complement the scientific community and policy makers for environmental protection and public management, not only to assess the impact of the outbreak on air quality, but also for its effectiveness as a simple alternative program of action to improve air quality.

Keywords COVID-19 · Mato Grosso do Sul · Air quality · Remote sensing · Human activities

Introduction

On December 31, 2019, Chinese authorities informed the World Health Organization (WHO) of an unknown pneumonia outbreak. As of January 23, the city of Wuhan, China, was quarantined, and, as of January 24, restrictive measures to prevent the spread of the infection began to

be introduced in many cities across the country. Transport links with several megacities have been limited, quarantining 60 million people in 17 cities in Hubei province. There were cases recorded at each unit at the provincial level in China; a few weeks later, the virus spread globally first to other Asian countries and later to North America, Europe,

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and other countries. WHO announced the pandemic of this disease on March 11.

The new type of coronavirus was found to be almost 70% identical to SARS-CoV (severe acute respiratory syndrome coronavirus) (Hui et al. 2020). The new coronavirus was initially designated with the code 2019-nCoV and, as of February 11, was renamed SARS-CoV-2 (WHO 2020). The infectious disease it caused was called COVID-19 (World Health Organization 2020). A striking feature of the current pandemic that makes fighting difficult is its long incubation period, which is usually about 5 days, but can last from 2 to 14 days (CDC 2020; Holshue et al. 2020). In severe cases of the course of the disease, COVID-19 can cause pneumonia, acute respiratory syndrome, kidney failure, and even death (Perlman 2020). Therefore, on June 5, 2020, the total number of COVID-19 cases exceeded 6.5 million and more than 387,298 deaths worldwide (WHO 2020).

With the blockade of countries, industrial activity stopped worldwide. Among the sectors of the economy, transport was most affected due to the blockade. Road and air transport have been disrupted, as many governments have severely restricted the movement of people (Muhammad et al. 2020). In addition, the pandemic affected not only the transport sector, but also the industrial and manufacturing sectors. Global oil demand has plummeted, and prices have plummeted as industry and transportation sectors around the world have stopped. The global outbreak and the spread of COVID-19 not only seriously threatened public health, but also impeded global economic growth (Wang and Su 2020; Wu et al. 2020).

This analysis of initial data suggested that government policies that directly reduced human activity, commercial demand, and transport could effectively and quickly reduce atmospheric pollution and urban air quality (Filonchik and Hurynovich 2020; Jribi et al. 2020; Xu et al. 2020a; Zhu et al. 2020). In other words, environmental pollution would increase with economic growth. In general, the meaning and consequences of a blockade were still poorly understood and studied and could probably play an important role in restoring air quality.

Governments, scientists, and experts have proposed protocols to curb the proliferation of the virus, such as washing your hands carefully, proper etiquette for sneezing and coughing, self-isolation, social detachment, quarantine, and complete blocking (Schimit 2021). In Brazil, policies of social isolation, closure of part of the commercial and industrial sector started in March 2020. However, divergences between state and federal governments were radically different, in which the federal government encouraged the reopening of all economic and industrial activities, while governors were more restrictive with regard to activities pertaining to functioning (Rodríguez Perón and Rodríguez Izquierdo 2021). In any case, the year 2020 in Brazil

oscillated between more or less restrictive measures in several locations. At the end of 2020, the easing of social isolation and the reopening of commercial and industrial activities caused an increase in the number of accumulated cases of COVID-19 in most Brazilian states, including Mato Grosso do Sul (Lobo et al. 2020).

This dynamic between the national blockade-easing-opening during the COVID-19 pandemic era provided a unique opportunity to work towards understanding the influence of commercial and industrial activities on air quality in Brazilian regions. Therefore, a quantitative assessment of air pollution was necessary to ultimately take steps to limit air quality, especially when such alternative control measures were needed.

The creation of atmospheric nitrogen dioxide (NO_2) is mainly related to the partial combustion of fossil fuel, exhaustion of motor vehicles, burning of biomass, soil emissions, and natural rays (Richter and Burrow 2002; Cheng et al. 2012). It has a fundamental role in the formation of tropospheric ozone (O_3) through a complex set of reactions with oxygen and free radicals generated from volatile organic compounds (VOCs) in the presence of sunlight (Crutzen 1979; Odman et al. 2009). It is also a source of tiny particle pollution, as well as acid rain and photochemical summer smog (e.g., WMO 2000; Pilar et al. 2010; Shon et al. 2011). Tropospheric NO_2 has detrimental influences on human health, plant growth, and climate change. Several epidemiological studies have shown a strong relationship between long-term exposure to NO_2 and decreased respiratory function (Panella et al. 2000; Smith et al. 2000). There is also a strong relationship between NO_2 emission and mortality, as reported in studies of daily time series (Samoli et al. 2006). NO_2 in the troposphere is removed mainly by its reaction with the hydroxyl radical (OH). NO_2 concentrations are also highly correlated with other pollutants, emitted by the same sources or formed through complex reactions in the atmosphere (Brook et al. 2007). Therefore, a complete spatial coverage of the NO_2 level in the soil is necessary for the assessment of exposure.

Several studies report on the economic decline during the pandemic (Gopinath 2020; McKibbin and Fernando 2020; Fernandes 2020; Wang and Su 2020) and the current state of air pollution during the pandemic (Wang and Su 2020; Gautam 2020; Collivignarelli et al. 2020; Tobías et al. 2020; Sicard et al. 2020). The impact of COVID-19 on various air pollution parameters has been studied for several countries and cities. However, according to the authors' knowledge, no similar research work has been carried out in an African or Arab country to date. In addition, the impact of COVID-19 on other environmental indicators, such as environmental noise, medical, and municipal waste, has rarely been discussed in the literature. Therefore, in this study, we analyzed the changes that occurred with NO_2 over MS, focusing on eight cities (Campo Grande, Dourados, Três Lagoas,

Corumbá, Coxim, Porto Murtinho, Ponta Porã, and Chapadão do Sul) during the coronavirus pandemic (2020) compared to the pre-pandemic reference period (2015–2019). An important contribution of the article is the discussion of the positive and negative consequences that encompass various environmental indicators. The uniqueness of this study is also that the containment actions implemented by the government of Mato Grosso do Sul to control the pandemic COVID-19, government containment measures, the impact on the economy in the state, and energy consumption to effectively assess the effect on studied environmental indicators.

This study is an attempt to evaluate the usefulness of the block as an alternative strategy to reduce air pollution in the state of Mato Grosso do Sul (MS), Brazil. The MS is located in the central-western region of Brazil, being one of the most relevant states in the sugarcane industry (Tomei et al. 2020), eucalyptus biomass (Nogueira et al. 2021). Therefore, the Ministry of Health suffered impacts of the pandemic in industrial economic terms, in addition to those resulting from the contamination of its population by COVID-19 and its consequences (sick leave, hospitalizations, and deaths, among others). In this sense, the main objective of this study is to compare NO₂ concentrations in the period before the pandemic and during the implementation of COVID-19 preventive control measures. By focusing on the state of MS, this study is expected to be a real complement to the scientific community and policy makers for environmental protection, not only to assess the impact of the blockade on air quality, but also for its effectiveness as a program, simple alternative action to improve air quality.

Data and methods

For comparison, two sets of NO₂ monthly concentration data were selected: from 2005 to 2019, relating to the pre-pandemic period, and in 2020, a pandemic period.

NO₂ data

NO₂ emission data obtained from the ozone monitoring instrument (OMI) on board the AURA satellite launched in 2004 as part of NASA EOS (Earth Observation System), which performed measurements of solar radiation reflected by the atmosphere and the surface, were used in the range of 270 to 500 nm and with a spectral resolution of 0.5 nm. The width of the recorded surface band, which is about 2,600 km, and the satellite's orbital period of 98.8 min, allow measurements to be made on a global scale and cover almost the entire earth's surface in one day. In OMI mode, designed for shooting on a global scale, the pixel size when shooting in the nadir direction is 13 × 24 km along and along the firing range, respectively (Levelt et al. 2006). Measurement data from the spectrometer was used to determine the vertical NO₂ profiles.

As for NO₂, the OMI instrument made it possible to determine its total content in the vertical column of the atmosphere as the total number of NO₂ molecules between the Earth's surface and the tropopause per unit area (Boersma et al. 2004). Research errors in remote, unpolluted areas were due to uncertainties in spectral adjustment and ($0.7 \times 10^{15} \text{ cm}^{-2} \cdot \text{molecules}$) (Boersma et al. 2007). The NO₂ content in the vertical column of the atmosphere was calculated by dividing the inclined content by the air mass value of NO₂, which depended on a series of parameters, including the geometry of the observations, the surface albedo, the shape of the vertical profile of NO₂, and cloud characteristics (height, density, and sky cover) (Boersma et al. 2004). NO₂ data was provided only if the radiance fraction of the cloud did not exceed 0.3 (that is, near a clear sky) and the solar zenith angle > 85° to ensure data quality. In this study, we used Aura/OMI NO₂ level 3 daily data products with a spatial resolution of $0.25 \times 0.25^\circ$ to study the NO₂ emission in the municipalities of (Campo Grande, Dourados, Três Lagoas, Corumbá, Coxim, Porto Murtinho, Ponta Porã

Table 1 Descriptive analysis of the historical NO₂ series for the cities of Campo Grande, Dourados, Três Lagoas, Corumbá, Coxim, Porto Murtinho, Ponta Porã, and Chapadão do Sul for the period from 2005 to 2020 (molec/cm²)

Variable	Count	Mean	StDev	CoefVar	Minimum	Q1	Median	Q3	Maximum	Skewness	Kurtosis
C Grande	192	2,9809	0,3974	13,33	2,3021	2,691	2,8694	3,2106	4,2676	0,9	0,39
Dourados	192	2,9867	0,4024	13,47	2,1809	2,6886	2,8993	3,2353	4,2582	0,73	0,16
Três Lagoas	192	2,9364	0,395	13,45	2,1097	2,6529	2,8717	3,1657	4,4066	0,69	0,23
Corumbá	192	2,9062	0,7002	24,09	1,9611	2,4561	2,6429	3,2226	5,5537	1,66	2,56
Coxim	192	2,9521	0,487	16,5	2,2614	2,5872	2,8458	3,2617	5,0177	1,2	1,72
P. Murtinho	192	3,0353	0,6735	22,19	1,9915	2,5617	2,8148	3,3558	6,0755	1,46	2,66
Ponta Porã	192	3,0385	0,5114	16,83	2,104	2,657	2,9357	3,3458	5,6076	1,33	3,08
C. do Sul	192	2,9454	0,4219	14,32	1,9355	2,6278	2,8953	3,1815	4,3188	0,67	0,34

Fig. 1 Spatial distribution of columnar NO_2 concentration in MS before (2005–2019, left panel) and during (2020, right panel) in the COVID-19 period

Fig. 1 (continued)

Fig. 1 (continued)

Fig. 2 Heat map of the amount of fire occurrence in MS (upper) and Pantanal (lower) between 2005 and 2020

and Chapadão do Sul). OMI Level 3 NO_2 data from the NASA GES DISC file.

Results and discussion

Table 1 shows the descriptive analysis of the mediated spatial series of oxygen dioxide concentration for the period from 2005 to 2020.

Spatial distribution of tropospheric concentrations of NO_2 in MS

The temporal evolutions of the total NO_2 of the column from January 2005 to December 2020 are shown in Fig. 2, where the monthly averages were plotted. The NO_2 of the local tropospheric column increased by 0.03% (from January to December) from 2005 to 2020. The highest values of tropospheric NO_2 occurred in 2015 with 3.08 E15/cm² molecules.

Fig. 3 Temporal variation of the NO₂ concentration time series (mol/cm²) for the cities of Campo Grande, Dourados, Três Lagoas, Corumbá, Coxim, Porto Murtinho, Ponta Porã, and Chapadão do Sul for the period from 2005 to 2020

The tropospheric concentrations of NO₂ were studied in the MS before and during the blocking period. The average tropospheric NO₂ level during the years 2005–2020 was 2.95E15 mol/cm²; for the period 2005–2019, the average was 2.88E15 mol/cm², and for the year 2020, the average was 2.29E15 mol/cm² with a 20% decrease from the year 2020 to the average for the years 2005–2019. The reduction values for the cities were as follows: Campo Grande (4%); in Corumbá, there was an increase of 19%, it is noteworthy that there was a big burn in the Pantanal; Dourados reduced by 1.8%; and in Três Lagoas, there was a reduction by 14.2%. Table 1 shows the especially average tropospheric NO₂ concentrations over the MS, and Fig. 2 indicated the spatial distribution of the tropospheric NO₂ concentrations in the MS, before and during the pandemic period. The spatial distribution of NO₂ over the DM showed hot spots of NO₂, mainly in urban areas, charcoal, and in thermal plants. NO₂ pollution is strongly influenced by the type of economic and development activities during the pandemic; although transportation and industrial activities were restricted and energy generation and biomass burning remained active, adding to atmospheric NO₂ emissions, it also identified thermal plants and industrial zones as the main hot spots for NO₂ emissions in MS.

The seasonal concentration of NO₂ is determined by the variability of weather conditions, atmospheric chemistry, and emissions (Souza et al. 2019; Souza et al. 2021). In regions that have strong anthropogenic NO_x emissions, a maximum expected NO₂ in winter and a minimum NO₂ in summer can generally be observed (Figs. 1 and 2). The general pattern of annual variation of the NO₂ tropospheric column. Peak values generally appear in August and September, and low values appear in January through May. For anthropogenic emissions, the maximum values generally appear in August, due to the need to clear pasture with fires, and the minimum values generally appear in June. Emissions in September were higher than in June due to the considerable biomass burning activity in the Pantanal, Cerrado, and Atlantic Forest biomes, or the production of NO_x from lightning in the dry season. The NO₂ of the lower tropospheric column in January to June can be attributed to reduced traffic and industrial activity.

The aforementioned seasonal characteristics of the NO₂ distribution are mainly linked to the OH and the frequency of NO₂ photolysis. The primary source of OH radicals is the photolysis of O₃ and other species such as nitrous acid and aldehydes (Ordóñez et al. 2006). The higher winter

values are probably the result of a decreasing loss of NO₂ by reaction with OH (the main process of loss of NO_x in the lower troposphere), and a lower rate of photolysis to deplete NO₂ due to less sunlight in winter, and possibly also due to higher winter emissions (Jaeglé et al. 2005). On the other hand, in the lower stratosphere, the reactions of NO₂ + hν → NO + O and NO + O₃ → NO₂ + O₂ control the NO_x transformation processes. Higher NO_x and lower hν make the reaction of NO + O₃ → NO₂ + O₂ easier in winter, which increases the concentration of NO₂ in the atmosphere.

Biomass burning in MS and its association with NO₂ concentrations

Biomass burning events mainly included forest fires, being observed during the study period throughout the MS, mainly in the year 2020 in the Pantanal region (Corumbá). These biomass burning events were identified mainly in the southwest (SW) of the MS. In the Pantanal biome, anthropogenic fire has been an efficient and inexpensive tool (Silio-Calzada et al. 2017; Schulz et al. 2019) to remove native vegetation before grazing or cultivating, stimulating the growth of native grasses or the establishment of new pastures (Evans et al. 2014; Bergier et al. 2019; Schulz et al. 2019). Beef cattle is the main economic activity in the Pantanal (Soriano et al. 2015). The increase in the number of fire fire focus in the Pantanal is strongly associated with economic activity, mainly in extensive agriculture, based on natural pastures that are burned to enable the regrowth of grass — destined for feeding cattle — when rain comes. Some studies have mentioned that the majority fires occur due to anthropic causes (Santos and Nogueira 2015; White and White 2016; Clemente et al. 2017; Oliveira- Júnior et al. 2020).

The situation is even more dramatic: in the period 2005–2019, where there were a total of 95,534 fire focus with an annual average of 6,369 fire focus of fire, and for the year 2020 it was 12,080 fire focus, with an increase of 100%. If these trends continue, there will be devastating consequences in the long run due to the release of millions of extra tons of carbon dioxide, nitrogen dioxide, etc., loss of species and destruction of vital ecosystems. In addition, fires pose a risk of serious health problems, in addition to threatening local livelihoods. These numbers show the fragility of the Pantanal, Cerrado, and Atlantic Forest biomes in the face of changes in the region's rainfall regime. The main reason given for the record burning in the Pantanal is a severe drought that also affects the region, after the rainy season in 2020 has already been marked by low rainfall. Many Pantanal areas that should still be drenched in August have

Fig. 4 Temporal variation of the NO₂ concentration monthly time series (mol/cm²) for the cities of Campo Grande, Dourados, Três Lagoas, Corumbá, Coxim, Porto Murtinho, Ponta Porã, and Chapadão do Sul

become overgrown with dry vegetation, which has contributed to the proliferation of fire.

Changes in economic activity

From the end of 2019 to the present, the COVID-19 epidemic has spread around the world and aggravated the epidemiological situation, bringing serious consequences to human health (Xu et al. 2020a, 2020b). To eliminate the spread of the epidemic, the Government of Mato Grosso do Sul decided to implement measures to control and prevent the spread of COVID-19. The cities of Campo Grande, Dourados, Três Lagoas, Corumbá, Coxim, Porto Murtinho, Ponta Porã, and Chapadão do Sul with approximately 1,256,086 inhabitants were influenced by the restrictions. Air and road traffic between cities was limited. Subsequently, different types of preventive measures were taken in all regions of the country. The production of several companies in the state was suspended. To contain the statewide epidemic, restrictions on population displacement were adopted. In cities, the creation of entire networks of control and patrol areas was started to quickly identify and isolate patients with suspected cases of COVID-19 infection, as well as those who came into contact with them. The restriction measures included driving restrictions on all non-emergency vehicles. The introduction of strict measures to contain the spread of COVID-19 (forced self-isolation, quarantine, border closure and production, and air traffic limitation) could have not only a positive impact on the environment, but also a reduction in the consumption of 11% electricity, but also led to a reduction in the growth economy. The COVID-19 outbreak had some negative effects on the economy. Therefore, the above prevention and control measures may be closely related to air quality.

Spatial distribution of air pollutants

Air pollution is one of the main environmental health problems that affect everyone in low-, middle-, and high-income regions. Air pollution is one of the main risks to environmental health. The lower the levels of air pollution, the better the health of the population with cardiovascular and respiratory diseases, both in the long and short term. Therefore, it is very important to constantly monitor air quality to assess the impact of pollutants on human health (Souza and Da Silva Santos 2020; Souza et al. 2018a, 2018b).

This study will focus on the state of Mato Grosso do Sul (MS), in the Midwest region of Brazil, based on the largest cities (Campo Grande, Dourados, Três Lagoas, Corumbá, Coxim, Porto Murtinho, Ponta Porã, and Chapadão do Sul) (IBGE 2021). The average columns derived from NO₂ satellite in January to December 2005–2019 and 2020 are shown in Table 1 and Figs. 1 and 2. High concentrations of pollutants have been reported mainly in western MS in the Corumbá region. Highlight to counties Grande, Dourados, and Três Lagoas, being subject to high concentrations of pollutants, although lower than in western MS.

The concentration of NO₂ varied in the period 2005–2020 (Fig. 3), where the main sources were the combustion processes (heating, power generation, operation of the car engine) and high concentrations of NO₂, which are located in highly urbanized. Due to its high solubility, the presence of NO₂ in the lower atmosphere was not great, depending on the season and the terrain; it can be up to 2 days (Renuka et al. 2020). This interval is too short for these air pollutants to spread globally. Therefore, in neighboring geographical areas, where large and moderate NO₂ emissions were carried out, a large difference in NO₂ concentrations could be observed in the atmosphere. It can be concluded that NO₂ appears mainly in highly developed industrial regions, and it is also possible to transport short distances from these regions with heavier pollutants to neighboring regions. Unlike NO₂, they had the highest levels in the 3 months of the year (September, October, and November). The high level of NO₂ during this period may be associated with additional emissions due to burning for cleaning and pasture formation (Oliveira- Júnior et al. 2020), mainly the burning that occurred in Corumbá in 2020.

Temporal variations of pollutants

The MODIS (MODerate Resolution Imaging Spectroradiometer) and AIRS (Atmospheric Infrared Sounder) sensors on the AQUA satellite and OMI (Ozone Monitoring Instrument) on the AURA satellite collect NO₂ data in the MS troposphere. Figure 4 shows temporal distributions of NO₂ in the months (January to December) of 2005–2019 and 2020 and the averages for the periods of 2005–2019 and 2020. Based on the restrictive measures taken between the period before and after the introduction of the measures. In general, the NO₂ concentration, both in the regions and in the entire MS, was significantly lower in June than in the previous period of 2020.

In the first 5 months of 2020, the average NO₂ concentrations declined compared to the same period in 2005–2019, with a minimum in June average for the

2020 series of 2,479 mol/cm² and 2,539 mol/cm² for the series from 2005 to 2019, when the two series grow until the month of August/September and when the series of 2020 reaches a peak of 3,362 mol/cm² (August) and decreases more slowly until the month of September (4,165 mol/cm²); from this month, it decreases until the month of December, reaching an average of 2,955 mol/cm², and for the historical series from 2005 to 2019, it grows from June (3,022 mol/cm²), and it reaches its peak in the month of September with 3,720 mol/cm² when it decreases until the month of December, reaching a value of 3,150 mol/cm². However, after having adopted strict restrictive control measures for COVID-19, which led to the suspension of many factories and enterprises, NO₂ emissions in MS were reduced, leading to an improvement in air quality, with the exception of the year 2020 in the months of September to November with a significant increase in NO₂, due to the fires that occurred in the Pantanal, region of Corumbá, followed by the reduction in the use of coal in the region of Três Lagoas, which led to a reduction in gas emissions.

In general, studies carried out in other regions during the blockade period also indicate a decrease in the concentration of pollutants. Thus, as a sharp drop in the concentration of PM_{2.5} (up to −29.8%), PM₁₀ (up to −22.8%), SO₂ (up to −18.1%), NO₂ (up to −54.3%), and CO (up to −64.8%) was observed in urban areas of São Paulo, Brazil, during the blockade (March 24 to April 20, 2020) compared to the same period in 2015–2019 (Nakada and Urban 2020). In Almaty, Kazakhstan, PM_{2.5} concentrations during the blocking period (March 19 to April 14, 2020) were reduced by 21% compared to the same period in 2018–2019 (Kerimray et al. 2020). A study in three cities in Hubei province (Wuhan, Jingmen, and Enshi) showed that in these cities in February 2020, when measures were taken to prevent and control epidemics, the mass concentrations of PM_{2.5}, PM₁₀, NO₂, SO₂, and CO were 30.1%, 40.5%, 61.4%, 33.4%, and 27.9%, and lower than in the same period of 2017–2019 (Xu et al. 2020a) and Nigam et al. (2021) in India.

Conclusions

After, the state of MS adopted restrictive measures in the control of COVID-19, which led to the suspension of many plants and enterprises, the emissions of the average tropospheric NO₂ level in Campo Grande, Corumbá, Dourados, and Três Lagoas during the years of 2005–2020 was 0.29E15 mol/cm², for the period

of 2005–2019, the average was 2.94E15 mol/cm², and for the year 2020, the average was 2.56 mol/cm² with a decrease of 14.9% from the year 2020 for the average of the years 2005–2019. The reduction values for the cities were as follows: Campo Grande (4%); in Corumbá, there was an increase of 19% (due to the great burning in the Pantanal); Dourados reduced by 1.8%; and in Três Lagoas, there was a reduction by 14.2%. This implies a close relationship between economics and environmental pollution. The decrease in economic activity and restrictions on transport can directly affect the change in energy consumption in the country and effectively reduced environmental pollution. Coal consumption at mills and refineries has returned to normal levels. The levels of NO₂ pollution measured from NASA satellites have returned to normal. This indicates that the intensity of human activity in the region had returned to the level of previous years. Although COVID-19 had a negative impact on economic activity and transport, on the other hand, it presented a reduction in human pressure on the environment, except in the year 2020, when we had a historic burn in the Pantanal.

However, it shows that short-term reductions and, in the long run, recovery from previous years are inevitable. Therefore, it is necessary to take measures to protect the environment during the economic recovery.

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Author contribution All authors participated in the preparation of the review and writing of the project, data collection, data analysis and writing of the article, review and writing of the article, and review of the article.

Data availability Atmospheric NO₂ data used in this study is available at <http://aura.gsfc.nasa.gov/lindex.html>.

Declarations

Conflict of interest The authors declare no competing interests.

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