Assessment of tropospheric nitrogen dioxide (NO_2) levels on the COVID-19 pandemic in Morocco

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Abstract. After being discovered in Wuhan, China towards the end of December, the novel infectious disease with human-to-human transmission (COVID-19) spread around the world and became a pandemic. Globally, there have been over 4 million 600,000 COVID-19 cases reported, and over 300,000 patients have passed away. Many of the pre-existing diseases that are impacted by long-term exposure to air pollution are also those that raise the risk of infection and mortality in individuals with COVID-19. Under the locking conditions, the current study investigates this correlation at the national Moroccan level. TROPOMI data from the Sentinel-5P satellite is utilized to map the distribution of NO_2 in the troposphere. According to the findings, three administrative regions with the highest tropospheric NO_2 concentrations harbored 60% of the COVID-19 infected cases. When viewed within the global context, these findings suggest that prolonged exposure to this contaminant may play a role in the infection, death, and dissemination of the COVID-19 virus.

1. Introduction

COVID-19 is a coronavirus 2 du disease that was discovered in the Chinese city of Wuhan, at the end of December 2019 [1]. The virus spread around the world in January 2020 and was classified as a pandemic by the World Health Organization (WHO) [2]. February 2020, several countries other than China experienced community epidemics, including South Korea, Iran, Italy, Germany and Spain [3]. L'épidémie devient alors une pandémie et, à la fin du mois de mars la moitié de la population mondiale entre en état de confinement [4]. By May 17, over 4 million 600,000 cases of COVID-19 had been reported worldwide, including 311 588 deaths[3] (Figure 1).

With the development of the epidemic, countries began to represent the recorded cases, in a sequential graph (i.e. the time on the abscissa and the cases confirmed on the ordinate) on a logarithmic scale. The exponential development of the epidemic (R0 N 1) begins when 20 new cases are reported for the first time (for example, in China on January 22, in Italy on February 23, in Spain on March 1 and in Morocco on March 15). As indicated by the World Health Organization, typical symptoms of a COVID-19 infection consist of fever, exhaustion, a dry cough, difficulty breathing, muscle aches, pains, and respiratory challenges. The approximate mortality rate associated with COVID-19 was 2-3%. [5]. This rate is estimated to be ten times higher than that of the flu. Advanced age [6], a history of smoking [7], hypertension and heart disease [1], diabetes, chronic respiratory disease and cancer [8]have been identified as risk factors linked to the development of the disease. Other recent research indicates that cytokine storm syndrome is associated with the death of many COVID-19 patients [9–10] .

Because of its contagious nature, COVID-19 has had an impact on people's lives and severely restricted their movements. Many countries have tried a mitigation strategy (one day after the start of the epidemic's exponential growth) to slow the spread of infection and reduce healthcare demands and the social perception of the epidemic. These measures were implemented in Italy on March 7 in Lombardy and on March 12 in the rest of the country. The measures were put in place in Spain for the whole country on March 14 (13 days following the onset of the exponential increase in the epidemic's spread, and in Morocco on March 20th, which was 5 days after the beginning of the exponential growth phase of the epidemic). These elements demonstrate the seriousness of the situation and the transmission of the virus by mobility. Recent research has confirmed that humans are responsible for transporting and spreading COVID-19 [11–13].

To hinder or reduce the transmission of the virus within Morocco, measures began on March 9, 2020 with the

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suspension of flights to several countries and of maritime links with Spain and France. Thus as a result of more than 90 miles of tests carried out until May 17, 2020, a total of 6798 cases were identified (approximately 184 cases /1 million of population) and the number of deaths registered so far was 192 (approximately 5 deaths /1 million of population) (Ministry of Health Morocco). According to this information, The percentage of confirmed cases relative to the total cases is approximately 7.6%. When compared to the global average of around 13.5% for other nations, Morocco's figure appears marginally lower. The recovery rate stands at 53.6%. Morocco's mortality rate is approximately 2.82%, which, based on the recorded number of tests, appears to be lower than the global average mortality rate of 7.04% in May 2009[14].

Apart from human-to-human transmission, air pollution and meteorological parameters are deemed viable factors. Many studies have examined the association between weather (wind speed, temperature, humidity) and death or severity of spread due to COVID-19, such as in Indonesia [4], China [15] Turkey [16] and even on a global scale [1,12,13,17]. These studies have suggested a correlation between these parameters and the transmission or mortality due to COVID-19.

Additional research indicates that prolonged exposure to air pollutants, particularly nitrogen dioxide (NO_2), a harmful element, can greatly exacerbate cardiovascular illness, oxidative stress in the respiratory tract, and asthma [18,19]. NO_2 is considered to be highly lethal to human health [20]. A high concentration of NO_2 is responsible for the generation of certain harmful secondary pollutants such as (HNO_3) and (O_3)[21]. NO_2 enters the atmosphere because of human activity, especially through the burning of fossil fuels. Road transport is considered the main source of NO_2 emissions[22]. One of the primary causes of air pollution worldwide is vehicle combustion engines, which release high concentrations of harmful pollutants like carbon monoxide (CO), nitrogen and sulfur dioxide (NO_2 and SO_2), particulate matter ($PM_{2.5}$), and ultrafine particles (UFP). These pollutants can also cause an inflammatory response in the respiratory tract and increase the risk of infection with viruses that target the respiratory tract [22–24]. According to a World Health Organization (WHO) report from 2019 alone, air pollution caused 4.2 million deaths and more than 103.1 million years of life loss [25]. The most recent information gathered by IQAir, which was included in the 2019 World Air Quality Report and the list of the most polluted cities, shows how particulate matter ($PM_{2.5}$) pollution has changed globally in 2019. By gathering and analyzing data from thousands of air quality monitoring stations worldwide, Hammes [26] comes to the conclusion that air pollution causes an additional almost 7 million deaths annually.

The observations that the epidemic COVID-19 has been significantly worsened by air pollution lend credence to this theory and resulted in more deaths than if the sky without pollution was the norm. They propose that due to the immune system's defensive reactions, persons who are exposed to high levels of persistent air pollution may be more vulnerable to contracting SARS-CoV-2. Others have investigated the connection between air pollution and SARS-CoV-2 lethality in England and have demonstrated a link between airborne pollutants emitted by burning fossil fuels and the risk of contracting COVID-19 and SARS mortality rates in England [27].

In an analysis of COVID-19 death figures, collected for more than 3,000 counties in the United States (98% of the population) until April 22, 2020, [6] Wu et al., (2020) found that an increase of only 1 μg/m^3 of $PM_{2,5}$ (particulate matter with aerodynamic diameter ≤2.5 μm) is connected to a COVID-19 death rate increase of 8% (95% confidence interval [CI]: 2%, 15%). The BBC reports that US researchers hypothesize that air pollution particles could serve as vectors for the spread of viruses.

This study aims to assess how Morocco's long-term exposure to NO_2 affects the country's coronavirus infection rate. This study examines data from administrative regions with high NO_3 concentrations as well as data at the national level. Furthermore, because the COVID-19 incubation period can range from one day to fourteen days, measurements made one year prior to the virus and during the incubation period are used to calculate the atmospheric NO_2 concentration. These assessments rely on data collected by the Tropospheric Monitoring Instrument (TROPOMI) aboard the Sentinel-5P satellite, managed by the European Space Agency. Such findings will enable an evaluation of the efficacy of the measures implemented by the Moroccan government to mitigate the COVID-19 outbreak.

2. Spatial distribution of NO_2

Using the precursor space satellite Sentinel-5, which has a spatial resolution of 5.5 km, the NO_2 concentration in the troposphere (from the surface up to approximately 10 km) was measured. The European Commission oversees and operates the satellite as part of the "Copernicus" initiative. It has a 16-day orbital cycle and orbits at 824 km in a sun-synchronous orbit. The TROPOspheric Monitoring Instrument (TROPOMI) on board the satellite provides (almost) complete coverage of atmospheric pollution caused by NO_2 and other pollutants like aerosols, O_3, SO_2, CO, CH_4, and CH_2O and aerosols [28]. Additionally, the satellite guarantees measurement continuity with existing and past atmospheric space missions (OMI, IASI, and SCHIAMACHY). When compared to data obtained from NASA's Aura satellite's OMI (Ozone Monitoring Instrument), the TROPOMI data exhibit superior accuracy and high spatial resolution.

Numerous studies have examined the capacity of data gathered by NASA using OMI on its AURA satellite and by ESA using TROPOMI on the Sentinel-5P satellite during this COVID-19 lockdown period. The released data provide fresh proof that human behavior modifications in response to COVID-19 have improved environmental quality and decreased NO_2 emissions. Images provide a comparison of NO_2 emissions in Wuhan in China [29-30], Italy, Spain and France [31], in India [28], in the five largest cities in Australia [32] and in eastern of United States [33].

In this sense, an international collaboration between NASA, ESA and the Japan Aerospace Exploration Agency (JAXA) is launched in a project called "Space Apps COVID-19 Challenge", to use open data to develop Innovative solutions to the problems posed by the global COVID-19 pandemic and examine how the virus spreads and what type of impact it has on Earth, ecosystems and cities [34].

Fig. 1. Geographic distribution of COVID-19 cases worldwide, as of July 10, 2020 (after [3]).

For this study, long-term exposure was defined as a period of one year before the COVID-19 epidemic. Spatial data were collected for free using the Sentinel-5P data Hub API [35]. The coverage of tropospheric NO_2 for this period was extracted using around thirty different images (from February 2019 to May 2020), then calculated the average concentration for each administrative region. Thereafter, only the maximum concentration value was used because of the differences in the size of the regions.

Sentinel 5P analysis was conducted using the Sentinels Application Platform (SNAP) architecture, which was developed in collaboration with Array Systems Computing, C-S, and Brockmann Consult for the European Space Agency (ESA). Because of its technological innovations namely, The Snap software, with its adaptability, mobility, modular rich client platform, universal EO data abstraction, tiled memory management, and graph processing framework, is ideal for the processing and analysis of Earth Observation data. For additional analysis, the output data is transformed to a GeoTIFF.

Figure 2 shows the concentration of NO_2 emissions in Morocco and its surrounding countries (Spain, Portugal, western Algeria, and northern Mauritania) March 2019 and March 2020. It indicates that emissions of NO_2 have decreased considerably. These results compared to previous studies in Spain for the same period [36], confirm that NO_2 emissions have decreased by 20-30% due to foreclosure, especially in big cities like Madrid, Barcelona and Seville.

The comparative analysis of TROPOMI data for March, April and May of 2019 and 2020 (Figure 3) shows that most of the NO_2 emissions focus on the north and west of Morocco. Visual analysis shows that NO_2 emissions decreased significantly during the lockout in Morocco, the Strait of Gibraltar and the south of Spain, mainly in the big cities due to the stopping of transport. The closure of global economic activity led to a reduction of the main sources of pollutants such as cars, trucks, factories, shipping and ports. A hot spot is located NW of Algeria near the Oran Oil refinery, marking its activity with a high tropospheric NO_2 level.

A detailed analysis of northern Morocco is presented in Figure 4. The figure shows the maximum tropospheric NO_2 levels in cities for the period from February 18, 2019, to May 8, 2020, analyzed from a series of Sentinel-5P satellite images using the TROPOMI instrument. The curves show that the level of tropospheric NO_2 reaches the highest level around Casablanca, followed by Marrakech and Tangier. Considering all cities, the highest levels dropped during the period of confinement dating from March 2020.

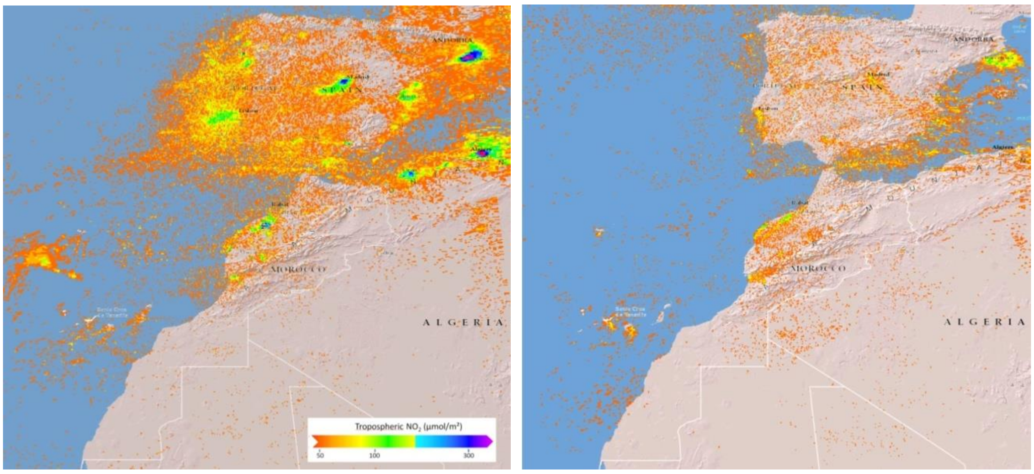

Fig. 2. NO_2 emissions in Morocco and surrounding countries in March 2019 and 2020

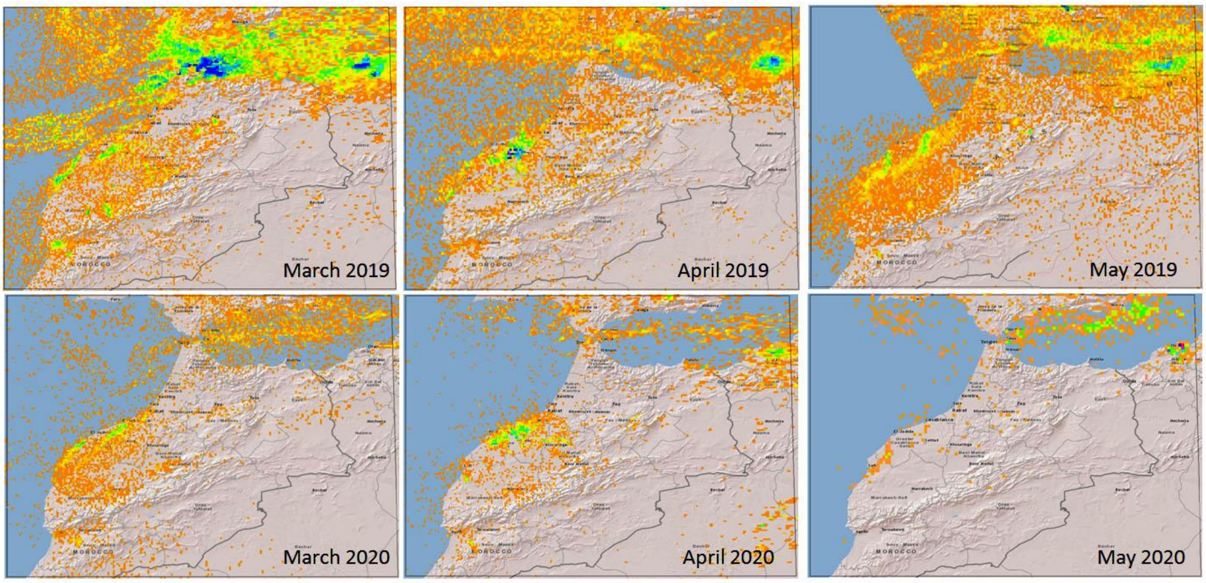

Fig. 3. Comparative analysis of NO_2 concentrations over northern Morocco (same legend as figure 2).

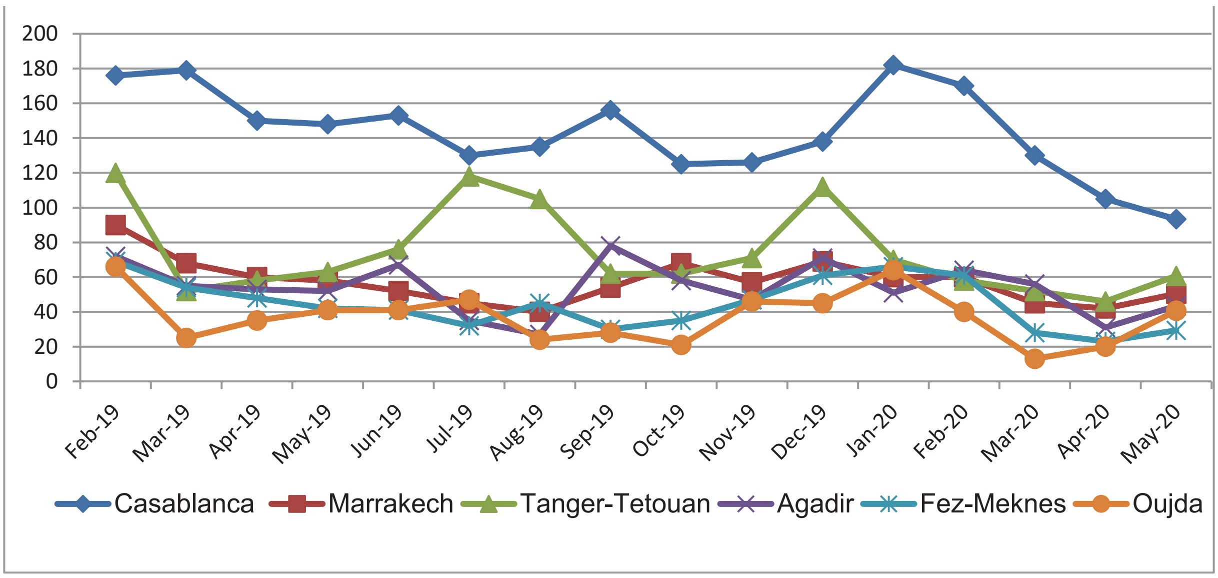

Fig. 4. Value of tropospheric NO_2 emissions extracted from TROPOMI Sentinel 5P by region in Morocco for the period from February 2019 to May 2020 (the values of the ordinate axis are in 10-3 µmol).

3. Results and discussion

These data show high rates in the Casablanca administrative region. This region has 6.9 million inhabitants, 20% of the population of Morocco. It is the first industrial region in Morocco in terms the number of industrial establishments and the creation of industrial jobs. It is also the most polluted area relative to other regions of Morocco, but remains moderate compared to other metropolises of the World. Reports of the World Health Organization [2] show that Casablanca has an average level of annual concentration of small particles and fine particles (PM_{10} and $PM_{2,5:}$ particulate matter with aerodynamic diameter ≤10 µm and ≤2.5 µm respectively) three times higher than the international standard (defined respectively by 20 µg/m^3 and 10 µg/m^3) [2]. PM_{10} and $PM_{2.5}$ consist of pollutants such as sulfate, nitrates, and black carbon, which can deeply penetrate the respiratory and cardiovascular systems, posing a significant health hazard. Elevated levels of $PM_{2.5}$ also influence daily weather patterns.

Marrakech comes in second place among the most polluted cities in Morocco with a small level of PM_{10} particles set at 46 µg/m^3 [2]. Marrakech is a tourist city and attracts many national and foreign visitors every year. According to statistics published by the Regional Council of Tourism of Morocco, tourist arrivals in the city of Marrakech totaled nearly 3 million visitors in 2019, an average growth rate of 8% compared to the previous year.

The mortality associated with pollution knows a gross increase of 2%. Consultations for asthma, bronchitis and another conjunctivitis also. In some areas where pollution reached its peak, this number increased up to 9%. Of the 2,200 deaths linked to air pollution in 2014, almost half (47%) were concentrated in Casablanca, followed by Marrakech and Tangier.
A comparison between the annual average $PM_{2,5}$ [2] before confinement and data through PurpleAir sensors [37] and IQAir [24] for May 2020, shows that the average level of concentration of fine particles has passed for Casablanca from 33 to 7.1 µg/m^3, from 28 to 9.1 µg/m^3 for Marrakech and from 24 to 15.1 µg/m^3 for Tangier. A similar assessment of air quality, conducted by the Department of Environment of the Moroccan Ministry of Energy and Mines and the National Directorate of meteorology (DMN) based on data from an air quality monitoring station in the city of Marrakech reported a decrease of 55% for NO_2, 70% for CO and 67% for particles in suspension (between November 2019 and April 8, 2020). These percentages can provide some clues on the development of the first cases of the virus movement.

These same cities recorded the highest rates of COVID-19 cases in Morocco (Figure 5). The figure lists the situation on May 14, 2020 and shows that nearly 61% of the total numbers of cases are located in the administrative regions of Casablanca (28%), Marrakech (18%) and Tangier (14%). These data come from the Ministry of Public Health of Morocco [38]. This resource provides the most comprehensive national reference on COVID-19 in Morocco, offering details on infection cases and daily fatalities for every region.

Data indicates that since the onset of the COVID-19 pandemic in Morocco, the Casablanca region has consistently reported the highest number of infection cases, followed by Marrakech, Tangier and Fez-Meknes regions. These regions experienced an acceleration of the epidemic linked with an R0 = 1.22 (Figure 6). A second group of regions gradually succeeded in moving away from the crisis zone with a relative stabilization of the evolution of the epidemic with an R0 = 1.1. In the third and last group (The regions of Laâyoune Sakia EL Hamra, Guelmim Oued Noun, and Dakhla Oued Eddahab), the epidemiological situation is controlled and the R0 is approximately 0.5.

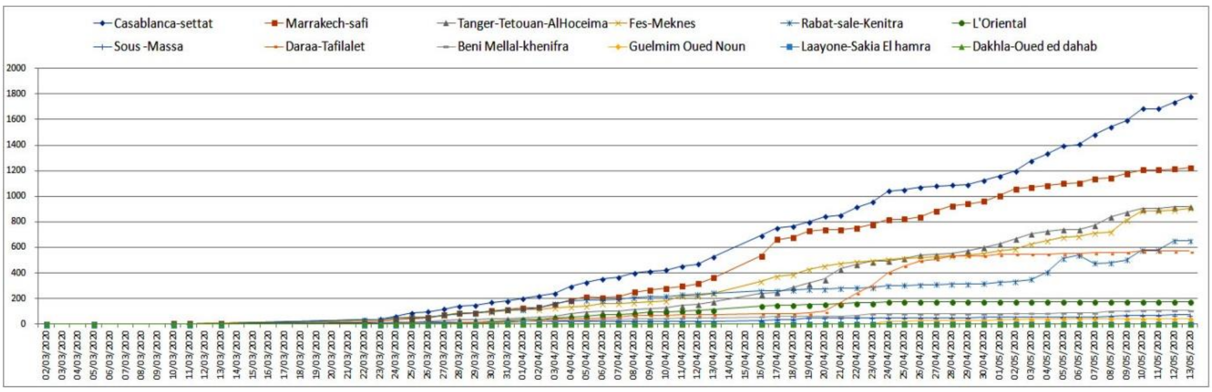

Fig. 5. Monitoring daily COVID-19 infections by administrative region in Morocco (Situation from March 02 to May 14, 2020).

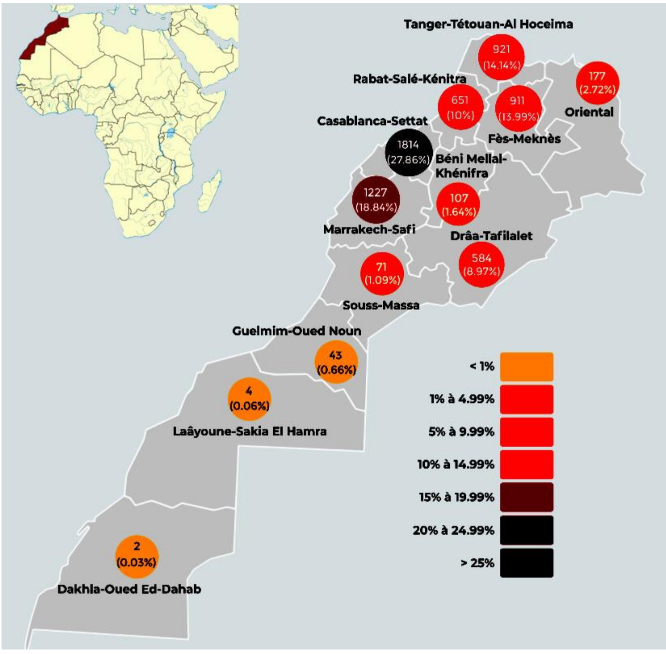

Fig. 6. COVID-19 epidemic situation by administrative region in Morocco (Situation from March 02 to May 14, 2020) (Medias24.com).

4. Conclusion

The findings of this research can be succinctly summarized. Firstly, tropospheric NO2 emission data correlates with actual air quality pollution levels observed in the field. The regions with the highest levels of NO2 emissions, notably Casablanca, Marrakech, and Tangier, are characterized by significant industrial and manufacturing activities, as well as heavy road and air traffic. Secondly, these same regions exhibit the highest number of confirmed COVID-19 cases. These findings depict a scenario where cities with elevated pollution rates harbor populations potentially more susceptible to the virus. These outcomes align with previous studies that have identified a positive correlation between air pollution levels and the incidence of COVID-19 infections. However, face to the lack of data on patients affected by respiratory and cardiovascular diseases and recently infected with COVID-19, we cannot give statistics on the relationship between long-term exposure to nitrogen dioxide and the increased risk of COVID-19 infection and mortality. Future and detailed studies could further enlighten these observations by addressing other parameters such as age, race and ability in intensive care

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