COVID-19 and the Improvement of the Global Air Quality: The Bright Side of a Pandemic

Hamideh Habibi 1, Ripendra Awal 1, Ali Fares 1,* and Masoud Ghahremannejad 2

1 College of Agriculture and Human Sciences, Prairie View A&M University, Prairie View, TX 77446, USA; hahabibi@pvamu.edu (H.H.); riawal@pvamu.edu (R.A.)
2 Independent Researcher, Houston, TX 77024, USA; mghahremannejad@gmail.com
* Correspondence: alfares@pvamu.edu

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Abstract: The objective of this investigation is to study the impacts of the global response to COVID-19 on air pollution and air quality changes in major cities across the globe over the past few months. Air quality data (NO$_2$, CO, PM$_{2.5}$, and O$_3$) were downloaded from the World Air Quality Index project for the January 2019–April 2020 period. Results show a significant reduction in the levels of 2020 NO$_2$, CO, and PM$_{2.5}$ compared to their levels in 2019. These reductions were as high as 63% (Wuhan, China), 61% (Lima, Peru), and 61% (Berlin, Germany), in NO$_2$, CO, and PM$_{2.5}$ levels, respectively. In contrast, 2020 O$_3$ levels increased substantially, as high as 86% (Milan, Italy), in an apparent response to the decrease in titration by nitrogen monoxide and its derivatives. Significant differences in the weather conditions across the globe do not seem to impact this air quality improvement trend. Will this trend in the reduction in most air pollutants to unprecedented levels continue in the next few weeks or even months? The response to this and other questions will depend on the future global economic and environmental policies.

Keywords: air pollution; COVID-19; carbon monoxide; nitrogen dioxide; particle matter; ozone

1. Introduction

Air pollution occurs when harmful or excessive quantities of substances are introduced into Earth’s atmosphere. Particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO$_2$), ozone (O$_3$), and sulfur dioxide (SO$_2$) are common air pollutants. Among them, ozone (O$_3$) is a greenhouse gas [1]. Carbon monoxide (CO) and nitrogen dioxide (NO$_2$) are considered as indirect greenhouse gases due to low absorption in infrared; they might produce and/or destroy the concentration of direct greenhouse gases (methane and ozone most prominently) with chemical reactions in the atmosphere [2]. Without naturally occurring greenhouse gases, the average temperature of Earth’s surface would be about $-18^\circ$C [3] rather than the present average of 15 $^\circ$C [3]. There are two primary sources of greenhouse gas emissions: natural sources, e.g., volcanic eruptions, and anthropogenic sources resulting from human activities such as the combustion of fossil fuels that are responsible for about two thirds of the anthropogenic greenhouse gas emissions [4]. Data have shown that the air pollutant concentration is increasing at a higher rate since the second half of the 20th century [4] in response to economic growth across the globe. Environmental pollutants such as anthropogenically generated greenhouse gases depend on the extent of economic development [5]; the famous and widely examined environmental Kuznets curve theory suggests that as development and industrialization progress, environmental damage increases due to greater use of natural resources and higher emissions of pollutants [6]. In situ air quality monitoring stations and satellite observations have been used to identify the increasing trends in air pollution, such as trends in NO$_2$ over China due to the rapid economic and industrial development [7], or the impact of the 2008 economic crisis on air quality...
over Greece [8]. A minimum of a 20% reduction in NO2 concentration throughout Europe for the period 2005–2010 was reported by Castellanos and Boersma [9]. Further, a significant reduction in nitrous oxide concentrations has been documented across the U.S. during the economic recession of 2007–2009 [10].

The 2019 outbreak of coronavirus disease (COVID-19) has created a global health crisis and has had a severe impact on people’s lives globally. The virus was first observed in Wuhan in China, and it has spread across the world rapidly [11]. Figure 1 represents the global spatial distribution of the total number of COVID-19 confirmed deaths, as reported by the Institute for Health Metrics and Evaluation on 1 May 2020. The U.S., with almost 70,000 deaths, followed by Italy and the United Kingdom, with nearly 29,000 deaths each, are the countries of the COVID-19 epicenter.

In response to the COVID-19 pandemic, most of the countries have issued countrywide shelter-in-place, stay-at-home, closure, and shutdown orders, and border control measures. Figure 2 shows the map of the stay-at-home orders’ (lockdowns/shelter-in-place order) start dates across the U.S. and Europe overlaid on the total number of COVID-19 deaths at the time of the orders. The total number of confirmed deaths was extracted from World Health Organization (WHO) reports [12]; however, stay-at-home orders’ start dates for major countries were gathered from the Institute for Health Metrics and Evaluation (IHME) [13] and news outlets. This map could help to understand the impact of early social distancing in limiting the spread of coronavirus and fatalities. California, U.S., issued the shelter-in-place order on 19 March, with only 17 confirmed deaths across the state (Figure 2). As a result of the quick action, the state’s fatalities (~2000 according to Figure 1) are by far less than New York that issued a statewide stay-at-home order on 22 March when the total number of confirmed deaths passed 180 (Figure 2). The state of New York has seen almost 23,000 COVID-19 deaths as of 1 May (Figure 1). For instance, Finland issued the stay-at-home order on 18 March when no fatalities had been confirmed at the time (Figure 2), which resulted in only 250 confirmed deaths by 1 May (Figure 1).
Dramatic improvement in the global air quality occurred and was documented by several studies that reported improved air quality around the globe, including China [14–17], India [18,19], Spain [20], Brazil [21,22], and Malaysia [23]. Muhammad et al. [15] used NO\textsubscript{2} emission maps produced by NASA (National Aeronautics and Space Administration) and ESA (European Space Agency) before and after the coronavirus pandemic. They analyzed the lockdowns’ impact on environmental quality; their results reported a pollution reduction of up to 30% in some of the epicenters of COVID-19, such as Wuhan (China), Italy, Spain, and the U.S. Most of these recent studies are city- or country-specific using satellite-based data. While satellite-based measurements give a good view of pollution over a region, ground-based air quality data provide site-specific information on pollution levels people are experiencing daily. Thus, the objective of this work is to study the impacts of collective responses to COVID-19 on air pollution and air quality changes in major cities across the globe over the past few months in comparison with the same period of 2019. The analysis was conducted in May 2020.

2. Air Quality Indicators and Human Activities

Urban air pollution is initiated from natural and anthropogenic sources. In the areas prone to fires and dust storm such as arid regions, natural resources contribute significantly to local air pollution; however, the contribution of human activities including fuel combustion from motor vehicles, heat and power generation, industrial facilities, and municipal and agricultural waste sites far exceeds that of natural resources in any region [24]. Motor vehicles and industrial processes have been the leading cause of degradation of the global urban air quality, resulting in an excessive increase in the levels of some greenhouse gases and the Earth’s ambient air and ocean temperatures during the past half-century [25]. According to the WHO, particle pollution (PM), ground-level ozone (O\textsubscript{3}), carbon monoxide (CO), sulfur oxides (SO\textsubscript{2}), nitrogen oxides (NO), and lead are the six major air pollutants.

Currently, air pollution can cause significant problems for human health and the environment including the following: (1) long- and short-term exposures to some air pollutants are linked with many diseases that lead to a significant number of deaths, heart attacks, asthma attacks, bronchitis, eye irritation, cancer, mental health, skin diseases, hospital and emergency room visits, work and school days lost, restricted activity days, respiratory symptoms, and premature mortality; (2) contributions to acid rain; (3) damage to crops and surfaces of treasured buildings and monuments; and (4) damage to the protective ozone layer in the upper atmosphere [26–28].

![Figure 2. Stay-at-home orders’ start data across the U.S. and Europe with the total number of confirmed deaths at the exact time overlaid on public OpenStreetMap (https://www.openstreetmap.org) (generated in Tableau Public version 2020.3. https://public.tableau.com/s/).](https://example.com/figure2.png)
Fine particulate matter is one of the primary pollutants that public health officials care about the most because it is linked to asthma, lung cancer, and deaths from cardiopulmonary diseases. Nitrogen dioxide is mainly emitted by power generation and industrial and traffic sources that can increase symptoms of bronchitis and asthma, as well as leading to respiratory infections and reduced lung function and growth [28]. Carbon monoxide is a colorless and odorless gas where exposure at high levels can be harmful to human health by impairing the amount of oxygen transported in the bloodstream to critical organs [28,29]. Ground-level ozone is a secondary pollutant (not directly emitted) and one of the major components of smog. Breathing ozone can trigger a variety of health problems such as asthma, reduced lung function, and respiratory diseases. Aside from its health impacts, tropospheric ozone is a short-lived climate pollutant and one of the most important greenhouse gases [29]. Table 1 summarizes the air quality standards and limits values established by the WHO Air Quality Guidelines [30], the U.S. EPA National Ambient Air Quality Standards (EPA NAAQS) [31], and European Commission (EC) in Europe [32] for human health protection in urban areas.

| Pollutant | Averaging Time | Unit     | WHO | EPA NAAQS | EC |
|-----------|----------------|----------|-----|-----------|----|
| PM$_{2.5}$ | Annual mean    | µg/m$^3$ | 10  | 12        | 25 |
| PM$_{2.5}$ | 24-h mean      | µg/m$^3$ | 25  | 35        | –  |
| NO$_2$    | Annual mean    | µg/m$^3$ | 20  | 40        | –  |
| NO$_2$    | 24-h mean      | µg/m$^3$ | 50  | 150       | 50 (×35 *) |
| O$_3$     | Annual mean    | µg/m$^3$ | 40  | 100       | 40 |
| O$_3$     | 1-h mean       | µg/m$^3$ | 200 | 188       | 200 (×18 *) |
| CO        | Daily 8-h maximum | µg/m$^3$ | 100 | 138       | 120 ** |
| CO        | 8-h mean       | µg/m$^3$ | 10.35 | 10 | |
| CO        | 1-h mean       | µg/m$^3$ | 40.25 | ** | |

* Permitted exceedance each year. ** 25 days averaged over 3 years.

3. Materials and Methods

A list of the most polluted cities was created based on the 2019 world air quality report developed by IQAir [33]. Additional major global metropolitan areas were also added to the list to ensure a global reach of the current analysis. Median daily values of the major air quality parameters (over 24 h) from major cities across the globe were downloaded from the website of the World Air Quality Index (WAQI) project [34] for the January 2019–April 2020 period. The WAQI project collects all the air quality data from different publicly available weather stations and monitoring programs (from >12,000 continuous air quality monitoring stations on six continents covering 1000 major cities from over 100 countries such as Mexico, India, Iran, China, France, Chile, El Salvador, USA, South Africa, Viet Nam, Myanmar, Serbia, Russian Federation, Thailand, Indonesia, Guatemala, South Korea, Mali, Bosnia and Herzegovina, and the Netherlands). These data sets provide daily minimum, maximum, median, and standard deviation concentration values for each of the air pollutant species (sulfur dioxide, SO$_2$, nitrous oxide, NO$_2$, fine particulate matter, PM$_{2.5}$ and PM$_{10}$, ozone, O$_3$, and carbon monoxide, CO) as well as the main meteorological data (wind, temperature, and rainfall). It is worth mentioning that the data for each major city were computed based on the average (median) of multiple stations [34]. The selected pollutants are known for their harmful effect on human health and their known cause of severe environmental problems [12].

To determine the traffic reduction during the COVID-19 pandemic, daily urban congestion levels of several major cities were collected from the TomTom website [35]. The TomTom Traffic Index covers 416 cities across 57 countries on six continents and provides free access to city-by-city information. TomTom’s Traffic Index data come from a community of more than 600 million drivers who use TomTom tech in their navigation devices, in-dash systems, and smartphones around the world. We also included the mobility trend reports released by Apple Map [36] in this work. These data consist of a relative volume of directions requests by people living in a country, region, sub-region, or city.
compared to a baseline volume on 13 January 2020. Cities are defined as the greater metropolitan areas, and their geographic boundaries remain constant across the data set. The data feature daily changes in requests for directions in three different transportation types: walking, driving, and transit. We only used driving and transit types in the analysis.

The daily median of pollutants concentration and metrological data for 2019 and 2020 were used to determine the monthly average median. Only months with a minimum of 15 daily data points were included in the analysis. Then, we computed monthly changes in pollutant concentrations and metrological data in 2020 in comparison to those of 2019 to provide a quantitative measure of relative change compared to pre-COVID conditions. A python script was developed and used to extract, process, and plot most of the data. Furthermore, Tableau Public version 2020.2 software [37] was used for visualization. Percentage monthly changes for each parameter were mapped on public OpenStreetMap for the February–April 2019 and 2020 periods for better visualization of the results.

4. Results

The lockdowns and shelter-in-place orders including restricted social contact and the closing of restaurants, shops, and a large number of companies and administrative centers have impacted millions of people across the world and have brought economic crises; however, environmental quality temporarily has improved as transport activities which result in less energy consumption and lower oil gas demand have been reduced significantly in many countries. To evaluate the impact of the COVID-19 pandemic on the air quality and levels of pollutants around the world, the average changes in NO$_2$ (%), PM$_{2.5}$ (%), CO (%), and O$_3$ (%) for the February–April period in 2019 and 2020 are depicted in Figure 3. There is a notable decrease in the levels of NO$_2$ and PM$_{2.5}$ in 2020 compared to those in 2019 across the world. On the contrary, ozone levels increased in 2020 compared to their levels during the same period of 2019. Significant reductions in the levels of NO$_2$ and PM$_{2.5}$ are clear since February, especially across Europe, which could be a direct result of the slowdown in the economic activities, travel, and movement restriction that culminated with the closure of some educational facilities and gathering restrictions that started in February. Among all the pollutants, the most significant reduction was that of urban NO$_2$. Nitrogen dioxide is emitted as a result of fossil fuel combustion processes, mainly from street vehicle activities in urban areas. In contrast, the significant increases in ozone levels across the globe, especially during February and April (Figure 3d), are most likely due to the decreased titration by nitrogen monoxide NO, which is a derivative of NO$_2$ [8, 38].

The results of this study give an overview of the air quality improvement during lockdowns across the globe; however, there could be other mitigating factors that could have contributed to these changes in air quality, such as meteorological factors. Ten major cities have been selected to evaluate the air quality improvement across the globe, which are Wuhan in China, Seoul in South Korea, Seattle and Washington D.C. in the U.S., Sydney and Perth in Australia, Berlin in Germany, Milan in Italy, and Lima in Peru. In the following sections, the air quality improvement during the COVID-19 pandemic for the selected cities is discussed.
Figure 3. The average change (%) in the daily median of pollutants concentration: NO$_2$ (a), CO (b), PM$_{2.5}$ (c), and O$_3$ (d) between February, March, and April in 2019 and 2020 overlaid on public OpenStreetMap (https://www.openstreetmap.org) (generated in Tableau Public version 2020.3.: https://public.tableau.com/s/).

4.1. Congestion Levels and Mobility Trends

NO$_2$, CO, and PM$_{2.5}$ are pollutants that are emitted as a result of fossil fuel combustion processes, mainly from street vehicle activities in urban areas. Thus, their levels are closely related to the local...
emission sources; they are good indicators of the effect of lockdowns on the global air quality at the street level. Figure 4 shows that the congestion level in all the selected major cities dropped significantly in March and April 2020 compared to their levels during the same period in 2019.

![Figure 4](image)

**Figure 4.** The relative difference in average congestion levels (%) in 2020 from standard congestion levels in 2019.

The highest and lowest decreases in the congestion levels were recorded in Wuhan-CN (−91% in March 2020) and Perth-AU (−7%), respectively. The trends and magnitude of congestion levels for all the cities were almost similar except for Sydney and Perth Australia. The small reduction in their levels during February was followed by a considerable decrease in March and April 2020. However, the congestion levels in Sydney (18%) and Perth (16%) were high in February 2020 compared to the standard level in 2019.

The mobility (driving and transit daily activities) trend data released by Apple Map for January–April 2020 (Figure 5) are based on a compilation of anonymized and aggregated map search data retrieved from Apple mobile devices. Figure 5 shows a notable reduction in street vehicle and transit activities in the selected cities. On average, traveling (driving and transit) was reduced by −34% and −64% in March and April 2020, respectively. Driving rates in Milan-Italy (−76 to −82%) followed by Lyon-France (−44 to −72%) were the lowest compared to the other major cities during March and April. The mobility trends of all cities are almost similar (reduced from February to April) except for Seoul-KR. In Seoul-South Korea, the driving rates increased from March to April (−74% to −40%). These results confirm the direct impact of the lockdowns (stay home orders) and travel restrictions as a result of COVID-19 on reducing street vehicle activities in most urban areas.

![Figure 5](image)

**Figure 5.** Mobility changes (%) from baseline during January–April 2020. Driving data are the upper panel, and transit data are in the lower panel.
4.2. Air Quality Improvement

Figure 6 shows the monthly relative changes for NO$_2$ (%), PM$_{2.5}$ (%), CO (%), and O$_3$ (%) concentrations during February–March 2020 compared to the same period of 2019.

![Figure 6](image)

**Figure 6.** The average change (%) in the daily median of pollutants concentration: NO$_2$, CO, PM$_{2.5}$, and O$_3$ between February, March, and April in 2019 and 2020 for ten major cities across the globe.

4.2.1. Nitrogen Dioxide (NO$_2$)

The highest monthly reduction in 2020 NO$_2$ levels compared to 2019 was in Lima-Peru (−61%) during April 2020 (Figure 6). In Europe, NO$_2$ response was site-specific; Lyon-France (−46% in April) led, followed by Milan-Italy (−18% in April); however, Berlin-Germany (−1% in March and April) had the lowest reduction levels during these three months (Figure 6). Berlin-Germany had one of the highest reduction levels during February (−42%), but its NO$_2$ emission levels in 2020 increased and were almost similar to those of 2019 during March and April. Milan-Italy, one of the worst COVID-19-hit European cities, had a moderate reduction in NO$_2$ compared to Lyon-France and Berlin-Germany; they had registered the two highest NO$_2$ reductions in March 2020. Despite the large distances and differences in their weather conditions between Lyon-France and Lima-Peru, the trends and magnitude of their NO$_2$ concentrations were close.

In other words, NO$_2$ monthly median concentrations for Lyon-France and Lima-Peru were lower by −30% and −35% during February and by −46% and −61% in April, respectively. Sydney- and Perth-Australia and Seattle-Washington had the lowest reduction in NO$_2$ globally (Figure 6). Perth had a higher decrease during February (−26%), but the magnitude of that reduction decreased substantially in March and April. Sydney’s reduction levels were more comparable to those of Seattle-Washington than to those of Perth-Australia. The dynamics of NO$_2$ reduction for Washington D.C. were closer to those of Milan-Italy than to those of Seattle-Washington despite the difference in distances between them. NO$_2$ is mainly emitted as a result of fossil fuel combustion processes, primarily from transit and street vehicle activities. Consequently, its level is closely related to the local emission sources. Results in Section 1 showed a significant reduction in street vehicle activities and travel restrictions in these major cities. Recent studies also reported a reduction in NO$_2$ during the COVID-19 pandemic across the world due to the massive decrease in the use of fossil fuel [21,39–41]. For example, a 25.5% reduction (4.8 ppb) in nitrogen dioxide was observed during the 8 January–21 April period compared to 2017–2019 in the continental United States [39].
4.2.2. Carbon Monoxide (CO)

The primary sources of CO to outdoor air are combustion engines (e.g., cars, trucks, and other vehicles and machinery). Globally, the reduction in the levels of carbon monoxide during February–March 2020 as compared to that of 2019 (Figure 6) was lower than that of NO\textsubscript{2} during the same period of 2019 except for Lima-Peru. In Lima-Peru, carbon monoxide trends and levels (−38% in February, −54% in March, and −61% in April) were similar to those of Lima-Peru NO\textsubscript{2}. Reduction in CO ranged between −2.5% and −26% for Wuhan-China and reached −18% for Seoul-South Korea in March. Washington D.C. experienced a more than 50% increase in its CO level during February 2020 and then reached −4% in March 2020 and −20% in April 2020 compared to 2019. The CO for the three European cities was not available. In a different study, the impact of lockdowns on the CO level was investigated in Rio de Janeiro, Brazil [42]. The authors’ results also showed a significant reduction (30.3–48.5%) related to light-duty vehicular emissions. Overall, it seems the dynamics of CO in 2020 compared to 2019 were similar to those of NO\textsubscript{2} which is expected given the fact that NO\textsubscript{2} and CO are generated mainly by the same sources (combustion of fossil fuels). The results in Section 1 showed a significant reduction in street vehicle activities and travel restrictions in these major cities as observed by other studies as well [22,43].

4.2.3. Particle Matter (PM\textsubscript{2.5})

Consistent with the other two pollutants, PM\textsubscript{2.5} levels showed almost similar trends; however, there are some differences in the magnitudes for a few locations. The highest reduction in March–April 2020 compared to 2019 levels was observed in Sydney-Australia (−34.5% on average). These reductions were almost consistent with those in Perth-Australia (−25.5% on average), Wuhan-China (−31% in January), and Berlin-Germany (−35.5% in April) to some extent. The dynamics for the rest of the selected cities (Seattle-Washington and Washington D.C. in North America; Lyon-France and Milan-Italy in Europe) except Lima-Peru were almost comparable: a slight decrease during February 2020 followed by either a slight increase in another drop in March and April 2020 as compared to 2019 levels. The same trend of PM\textsubscript{2.5} was also reported in several recent studies [42,43]. This dynamic of PM\textsubscript{2.5} is expected because PM\textsubscript{2.5} is composed of fine particles made up of hundreds of different chemicals that are either generated from direct sources (construction sites, unpaved roads, fields, smokestacks, or fires) or are formed in the atmosphere as a result of complex reactions of chemicals such as sulfur dioxide and nitrogen oxides, which are pollutants emitted from power plants, industries, and combustion engines. A slowdown in the economic activities followed by a lockdown would substantially reduce the PM\textsubscript{2.5} contribution of the direct sources; however, it is not easy to predict the fate of the second source of PM\textsubscript{2.5}.

4.2.4. Ozone (O\textsubscript{3})

Ozone is a regionally sensitive secondary pollutant that is not directly emitted into the air; however, it is a product of the reaction of several factors simultaneously: nitrogen oxides (NOx, byproducts of NO\textsubscript{2}) availability and volatile organic carbon (VOC) availability in the presence of sunlight under specific weather conditions [38,44]. Thus, it is a complicated atmospheric air pollutant; the proportion of these interconnected chemicals regulates its level. The generation of ozone in the air depends on the VOC/NOx ratio. High NOx emissions mean a VOC-limited chemical regime, while significant VOC emissions (NOx availability) mean the contrary [45]. Generally, a VOC-limited environment is seen in urban areas with normal meteorological conditions where NOx emissions are dominant, but a NOx-limited regime is observed in rural areas [46]. Therefore, ozone concentration is expected to increase in urban areas with a VOC-limited chemical regime and NOx emissions reductions [46].

According to Figure 6, the trends and magnitudes of ozone concentration during February–March 2020 compared to those of the same period in 2019 were different in the major cities (Figure 6). O\textsubscript{3} increased during the lockdowns in Wuhan-China (31–50%), Seoul-South Korea (2–33%), and Milan-Italy (12–86%), while NO\textsubscript{2} significantly decreased (Figure 6) and temperature and wind speed (Figure 7) remained
almost constant in 2020 compared to 2019 in those cities except for Seoul-South Korea. Seoul had a higher temperature (6 to 10 °C) and wind speed (~2 mph) in March and April 2020 than in 2019. Milan-Italy (86% in February) followed by Wuhan-China (50% in February and March) had the most substantial increase in ozone concentrations, which could be a result of NOx disbenefits. The terms “NOx disbenefits” or “ozone disbenefits” refer to the ozone increases which can be a result of NOx emission reductions in the localized areas [38]. Seattle and Washington D.C. in the U.S. experienced, on average, 10% and 25% less ozone during the lockdowns (March and April) than 2019, respectively. The 2020 weather conditions in Seattle were almost the same as in 2019; however, the temperature in Washington D.C. increased by 8 °C in March 2020 and decreased by 4 °C in April 2020. O3 in Lima-Peru increased in March and then dropped in April 2020 despite there being no considerable changes in weather conditions during the two months. There were no significant changes in the ozone concentrations for Sydney-Australia, Berlin-Germany, and Lyon-France.

![Figure 7](image-url)

**Figure 7.** The monthly changes in median temperature (upper panel) and wind speed (lower panel) levels in the February–April 2020 period in comparison to their levels during the same period of 2019 in ten major cities across the globe.

5. Discussion and Future Projections

In response to the COVID-19 pandemic, most of the countries across the world have issued countrywide shelter-in-place, stay-at-home, closure, and shutdown orders, and border control measures. Therefore, in this study, we investigated the impacts of the global response to COVID-19 on air pollution (NO2, PM2.5, CO, and O3) and air quality changes in major cities across the globe from February to April 2020 compared with the same period in 2019.

Results of mobility trends for several large cities across the globe indicate a significant impact of the COVID-19 pandemic on the transportation sector [47,48] which is one of the main contributors to pollutants and greenhouse gas (GHG) emissions in urban areas. We also found that the driving requested by people living in Milan, Italy, dropped by 82% in April 2020, and in almost all selected major cities, the transit requests (bus or train on someone’s route) declined by around 75% in April. The restrictions reduced the global road transport and commercial flight activity by up to almost 50% (by the end of March 2020) and 75% (by mid-April 2020) compared to the 2019 average, respectively [48].

Current findings show that the levels of measured air pollution noticeably started to decline in February. Among all the pollutants, the most significant reduction was observed in urban NO2. The NO2 reduction varied from −5% to −44% in February, −0.4% to −63% in March, and −1% to −61% in April. The largest reduction in NO2 level (−63%) was reported in Wuhan, China, in March (almost two months since the city lockdown). We observed that the measured NO2 declined by almost −23% across the U.S. which was also reported in [39]. Satellite data from NASA also show a similar 30% reduction in NO2 during March in the urban northeastern U.S. [49]. Decreases in NO2 are likely associated with the slowdown of economic activities, people working remotely, limited domestic
travel, and movement restrictions that culminated with the closure of some educational facilities and gathering restrictions. Nitrogen dioxide is emitted as a result of fossil fuel combustion processes, mainly from street vehicle activities in urban areas. In contrast, the significant increases in ozone levels across the globe, especially during February and April, are most likely due to the decreased titration by nitrogen monoxide NO, which is a derivative of NO\textsubscript{2}. We had observed the air pollution reduction in response to the reduction in the activities of the transportation sector during previous health crises, such as SARS [47], and large-scale events such as the 2008 Beijing Olympics [50] and the 1996 Atlanta Olympics [51]. As reported in previous studies in China, Italy, Spain, France, and other areas of the world [15,52,53], our results also indicate a reduction in the levels of carbon monoxide during February–March 2020 as compared to that of 2019; however, its percent change is not as significant as that of NO\textsubscript{2}. The largest reduction in CO (−61%) was observed in Lima, Peru, in April. The PM\textsubscript{2.5} concentration also declined during the COVID-19 pandemic globally. Overall, the PM\textsubscript{2.5} reduction is larger than that of CO but less than that of NO\textsubscript{2}. The largest reduction in the PM\textsubscript{2.5} level (−61%) was observed in Berlin, Germany, in February, which might partially be related to the COVID-19 pandemic as the shelter-in-place order started in March; however, some restrictions were in place since February that resulted in a reduction in economic activities. The larger reductions in PM\textsubscript{2.5} concentrations were observed mostly in the countries that issued slowdowns or shutdowns for non-essential businesses early compared to those that did not take such action. This might explain the continued increase in the levels of this pollutant that could be generated from non-transportation such as food industries and biomass burning [39].

In contrast with CO, PM\textsubscript{2.5}, and NO\textsubscript{2}, we found that the ozone concentrations increased during February–April 2020 compared to those during the same months in 2019. This trend was also reported in other studies around the world [22,54,55]. An increase in O\textsubscript{3} could not only be related to the significant reduction in NO\textsubscript{2} concentrations [38] but also resulting from meteorological conditions [56]. We have conducted a limited study to identify the potential short-term impact of meteorological conditions (temperature and wind speed) on O\textsubscript{3} for several cities around the world; however, no significant changes in weather conditions were detected. The changes in pollutant concentrations depend on several factors, including emissions levels, meteorological conditions, transport, deposition, and atmospheric chemistry, so a direct relation might not be easy to find [22].

The COVID-19 pandemic has reduced levels of key pollutants because of the closure of factories and businesses, along with stay-at-home orders and social distancing that allowed fewer cars on the road and fewer planes in the sky. This study shows the impact of the surface transportation sector’s emissions on air quality, indicating that structural changes or regulatory bodies in the sector will lead to a significant improvement in air quality around the globe. Although we observe reductions in most of the gaseous emissions short after the shutdowns took place, it is important to assess the temporal variations and long-term trends of pollutant concentrations when analyzing for short-term differences in air pollutant concentrations [44].

It is expected that the air quality will keep improving if the lockdowns and restrictions continue; however, this is not a solution to air pollution that kills millions of people every year. An in-depth analysis is needed in the foreseeable future. Will this trend in air quality improvement continue, and for how long? Will humanity seize this opportunity to sustain this positive impact on air quality permanently? These are fundamental questions that could be further investigated. Meanwhile, the poor and most vulnerable people will suffer the most from both the health impacts and the economic crisis. The pandemic could show us how the future might look with less air pollution and help to evaluate the effects of the reduction in different emission sources and to assess further air quality policies.

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