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Review Article

Impact of COVID-19 Lockdown on Ambient Air Quality of Lucknow: Capital City of Most Polluted State in India

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ABSTRACT

The coronavirus disease 2019 (COVID-19) pandemic, caused by the new coronavirus SARS-CoV-2, struck India on January 30, 2020, in Kerala, with the first positive case, forcing a 4-month nation-wide lockdown from March 25 to May 31, 2020, followed by a period of unlocking. Unfortunately, in the month of March 2021, India was hit by a major second wave of the COVID-19 pandemic, prompting a state-wide lockdown. Lockdown was a curse for India's 1.39 billion people, yet it was a blessing for the environment. Because of the disastrous spread of coronavirus and consequent shutdown, many manmade activities were halted, allowing the ecosystem to flourish. The present article highlights the impacts of both the lockdowns on ambient air quality of Lucknow, Capital city of most polluted state in India. Air quality index (AQI) values for four hazardous air pollutants (particulate matter$_{2.5}$ [$PM_{2.5}$], NO_2, SO_2, and CO) were monitored and evaluated in the Lalbagh area of Lucknow during various phases of 1st and 2nd lockdown and the AQI value of $PM_{2.5}$ were further converted into concentration term ($\mu g/m^3$) to analyze a 24 h average variation. The lowest concentration of $PM_{2.5}$ was measured at 41.5 $\mu g/m^3$ during the first lockdown and 11.5 $\mu g/m^3$ during the second lockdown, resulting in a reduction in levels of $PM_{2.5}$. During the first lockdown, the highest and lowest recorded AQI values for gaseous pollutants, namely, NO_2, SO_2, and CO, were 35, 3, 10 and 0, 1 and 5, while during the second lockdown, the highest and lowest recorded AQI values were 30, 9, 20 and 20, 1,and 5, respectively. Explanatory explanations for the positive influence of meteorological discoveries in enhancing air quality during 1st lockdown and 2nd lockdown are also established in this study.

Key words: Air quality, Coronavirus, Coronavirus disease 2019, Lockdown.

1. INTRODUCTION

The city of Wuhan, China, became the epicenter of numerous pneumonia cases in late December 2019 as a result of a novel coronavirus, SARS-CoV-2, which causes an illness called coronavirus disease 2019 (COVID-19), name given by the World Health Organization in February 2020 [1], citing more than 118,000 confirmed cases and 4291 deaths in 114 countries, including India. Many precautions were advised ahead of time, such as maintaining social distance, wearing masks, and washing hands often, but the number of illnesses was increasing at an alarming rate. COVID-19 infection is thought to be aided by a variety of environmental factors, including air pollution, temperature, humidity, and wind speed [2]. A recent study by Bourdrel *et al*. highlights the direct impact of outdoor air pollution on COVID-19 severity and mortality through different mechanisms [3]. According to several researchers, air pollution impairs the immune system, allowing viruses to infect and replicate more easily. COVID-19 related epidemiological investigations suggest that the pollutants aiding for the spread of coronavirus infection include particulate matter (PM) and gaseous pollutants, namely, NO_2, SO_2,CO [4]. PM is a mix of small solid and liquid droplets having a diameter of 2.5 µm found in the air that can be inhaled and cause major health concerns. Construction sites, vehicle emissions, and industrial sites are all its sources. The source of SO_2 comes from the combustion of coal and oil in the atmosphere [4]. When inhaled, it causes respiratory difficulties as well as other heart-related issues such as ischemic heart disease, heart failure, and arrhythmia. NO_2, a dangerous gas largely found in metropolitan areas, is mostly created by automotive emissions [5]. When inhaled, it can lead to asthma, chronic obstructive pulmonary disease, and a variety of cardiovascular problems [6]. During the second wave of COVID-19 in India, where the maximum patients died due to shortage of oxygen, carbon monoxide, another toxic air pollutant became noticeable and it was thought to be one of the reasons in worsening the situation because when inhaled, it competes with oxygen by attaching itself to hemoglobin in red blood cells, starving key body organs including the brain and heart of oxygen, limiting their ability to function and worsening the health of COVID patients [7]. The Indian government implemented a number of critical measures and actions to reduce the infection rate, including a nation-wide lockdown. To prevent the infection from spreading further, Mr. Narendra Modi, India's prime minister, announced a nation-wide lockdown on March 24, 2020, for 21 days which was later extended till May 31, 2020 to interrupt the cycle of coronavirus infections. With the help of Figure 1, the various phases of lockdown 2020 can be comprehended. All non-essential services were halted across the country, including the shutdown of schools,

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colleges, industries, and transportation. The closure of schools, colleges and companies restricted vehicle traffic, reducing air pollution produced by automotive emissions such as NO_2, CO, and $PM_{2.5}$ [8]. As all forms of social, economic, and industrial activity abruptly ceased, nature took advantage of the situation and demonstrated remarkable improvements in ambient air quality. In late March 2021, just as nature was beginning to heal, India was hit by the terrible second wave of the COVID-19 pandemic. However, a comprehensive lockdown was not considered a good option this time; instead, state chiefs were given the option of a lockdown based on the growing number of COVID instances. Weekend lockdowns were first enforced on April 20, 2021 (Phase 1), but on April 30, 2021, the Uttar Pradesh government announced that weekend lockdowns would now extend to Mondays as well (Phase 2), citing an alarming increase in infection cases. Mondays were removed from weekend lockdowns on May 10, 2021 (Phase 3), due to a decrease in the number of COVID cases, followed by the elimination of Saturdays from the weekend lockdown on August 14, 2021 (Phase 4). Some partial relaxations with a restricted time frame were also introduced in the month of August. Finally, on August 22, 2021, weekend lockdowns were completely uplifted (Phase 5). Figure 2 depicts the different phases of Lockdown 2021.

The good side of lockdown can be attributed to the fact that the environment was reset globally as a result of the nation-wide and state-wide lockdown, which resulted in a drop in pollutant concentrations and better air quality [9]. Due to the restriction on movements of vehicles, release of dangerous air pollutants such as PM and carbon monoxide minimized [10]. The emergence of nitrogen dioxide, another hazardous pollutant, was restricted by the closure of industries and fossil fuel combustions [11]. This study examines the evidence for improved air quality as a result of lockdown and contrasts which lockdown had the most influence in improving air quality.

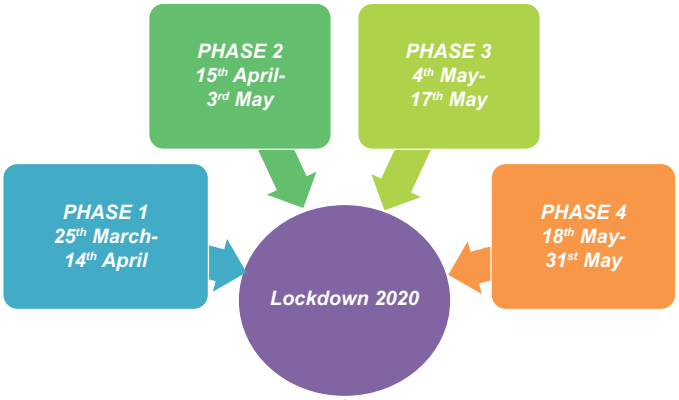

Figure 1: Different phases of 1st lockdown in the year 2020.

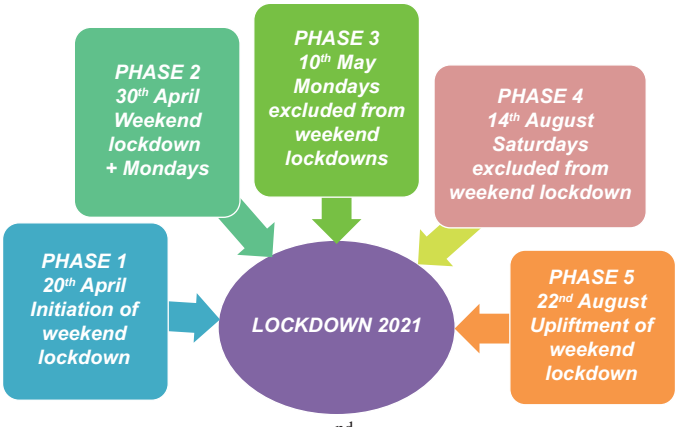

Figure 2: Different phases of 2nd lockdown in the year 2021.

2. MATERIALS AND METHODS

To examine the air quality during 1st and 2nd lockdown in the year 2020 and 2021, respectively, Lucknow, capital city of most polluted state in India was selected for the present study [Figure 3]. The topographical details of the selected city are given in Table 1. Lalbagh, Lucknow's center, historic, and business district, was chosen as the monitoring station.

The air quality index (AQI) values for four hazardous air pollutants, namely, $PM_{2.5}$, NO_2, SO_2, and CO, were collected during 1st lockdown in the year 2020 (March 25-May 31) and 2nd lockdown in the year 2021 (April 20-August 22). The AQI values of $PM_{2.5}$ were further converted into concentration term ($\mu g/m^3$) using an online AQI calculator (www.airnow.gov). With the help of Tables 2-5, daily average values of selected pollutants during 1st and 2nd lockdown can be comprehended. Tables 6 and 7 give the details of the meteorological data (Temperature, humidity, and wind speed) during 1st and 2nd lockdown. The recorded data were freely available on the internet (www.aqicn.org) and did not require any special permissions. The meteorological data were collected from (www.timeanddate.com).

3. RESULTS AND DISCUSSION

3.1. Average Concentrations of $PM_{2.5}$ During 1st and 2nd Lockdown

The average concentrations of $PM_{2.5}$ for 1st and 2nd lockdown are represented in Figure 4. The highest and the lowest concentration values of PM $_{2.5}$ for Lucknow during 1st lockdown were 186.8, 115.5, and 111.6, 100 ($\mu g/m^3$) and 25.4, 26.3, 27.7, and 41.5 ($\mu g/m^3$), respectively. The highest and the lowest concentration values of PM $_{2.5}$ for Lucknow during 2nd lockdown were 125.2, 117.4, 103.9, and 90.3 ($\mu g/m^3$) and 6.4, 7.2, 9.6, and 11.5 ($\mu g/m^3$), respectively. The sudden dip in the concentration value can be attributed to many factors such as rainfall, wind speed and temperature, restricted movements of people. The consistent decline in the concentration value can be observed for the months of July and August 2021, that is, during monsoon season in India. A sudden regressive trend was also obtained on off-days or on festival days, for example, a concentration value of 17.3 $\mu g/m^3$ was obtained on the May 14, 2021, the day on which festival of Eid was celebrated across the country. The overall $PM_{2.5}$ concentration figure for the second lockdown is lower than the first lockdown. The likely explanations are related to the catastrophic second wave of COVID, when the number of infection cases was at an all-time high and people were terrified to leave their homes, also later part of the 2nd lockdown was accompanied with the monsoon months, that is, July and August.

3.2. Average AQI Values for the Gaseous Pollutants (NO_2, SO_2, and CO)

Variations in gaseous pollutant concentrations can be impacted by a variety of factors, including vehicle traffic, construction and industrial sites, fossil fuel combustion, rainfall, temperature, and speed of the flowing wind in a particular area [13]. Since, Lucknow's Lalbagh is an epicenter of business districts, vehicular movement is

Table 1: Details of the selected city.

City	Lucknow
Monitoring station	Lalbagh
Population	37,64,619
Area (km^2)	631
Coordinates	26.84°N, 80.94°E

Table 2: Daily average AQI and concentration of $PM_{2.5}$ during 1st and 2nd lockdown.

PM 2.5				
1st Lockdown 2020	**Phase1**	**Phase 2**	**Phase 3**	**Phase 4**
	March 25–April 14	April 15–May 3	May 4–May 17	May 18–May 31
AQI	141.14±15.9	133.73±32.3	144.7±36.7	164±30.2
Concentration	55.55±15.9	59.24±29.4	70.74±36.3	88.01±37.1
2nd Lockdown 2021	Phase1	Phase 2	Phase 3	Phase 4
	April 20–April 30	May 1–May 10	May 11–August 14	August 15–August 22
AQI	161.63±21.4	142.7±18.3	96.55±26.6	103.87±17.3
Concentration	83.08±29.00	57.5±16.6	34.19±18.6	36.36±7.4

AQI: Air quality index

Table 3: Daily average AQI value of NO_2 during 1st and 2nd lockdown.

NO_2				
1st Lockdown 2020	**Phase1**	**Phase 2**	**Phase 3**	**Phase 4**
	March 25–April 14	April 15–May 3	May 4–May 17	May 18–May 31
AQI	6.66±2.00	7±0	10.5±8.1	4±3.9
2nd Lockdown 2021	Phase 1	Phase 2	Phase 3	Phase 4
	April 20–April 30	May 1–May 10	May 11–August 14	August 15–August 22
AQI	18.63±4.9	9.4±2.2	9.12±7.7	5.12±2.9

AQI: Air quality index

Table 4: Daily average AQI value of SO2 during 1st and 2nd lockdown.

SO_2				
1st Lockdown 2020	**Phase1**	**Phase 2**	**Phase 3**	**Phase 4**
	March 25–April 14	April 15–May 3	May 4–May 17	May 18–May 31
AQI	1.23±0.4	1.36±0.4	1.07±0.2	1.14±0.9
2nd Lockdown 2021	Phase 1	Phase 2	Phase 3	Phase 4
	April 20–April 30	May 1–May 10	May 11–August 14	August 15–August 22
AQI	2.72±0.6	4.1±0.9	3.70±1.5	3.37±1.5

AQI: Air quality index

Table 5: Daily average AQI value of CO during 1st and 2nd lockdown.

CO				
1st Lockdown 2020	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
	March 25–April 14	April 15–May 3	May 4–May 17	May 18–May 31
AQI	8.80±0.8	8.47±1.3	9.07±0.2	9±0
2nd Lockdown 2021	Phase 1	Phase 2	Phase 3	Phase 4
	April 20–April 30	May 1–May 10	May 11–August 14	August 15–August 22
AQI	7.1±2.3	9.1±2.6	10.05±3.4	8.11±0.3

AQI: Air quality index

observed throughout the day, resulting in significant variations in the concentration values of gaseous pollutants. It becomes interesting to note the changes in concentration of gaseous pollutants during lockdown period.

3.3. Nitrogen Dioxide (NO_2) Trends During 1st and 2nd Lockdown

The AQI values of NO_2 show a strong regression tendency, as before the lockdown period began, the highest AQI value for the Lalbagh region was determined to be 100, which is many times higher than the AQI values acquired during the lockdown period. The highest and the lowest recorded AQI values of NO_2 during 1st lockdown were 35, 14, and 10 and 4, 3, 1, and 0, respectively, and for the 2nd lockdown the highest recorded AQI values of NO_2 were 30, 27, 26, 20 and lowest recorded AQI values of NO_2 were 6.4.3.2, respectively. The imposed restriction on vehicular movements, restrictions on construction and industrial sites played a vital role in improving NO_2 levels in the

Table 6: Daily average meteorological data during 1st lockdown

Meteorological data during 1st lockdown in the year 2020				
1st Lockdown 2020	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
	March 25–April 14	April 15–May 3	May 4–May 17	May 18–May 31
Temperature (°C)	31.95±3.6	32.05±2.1	31.35±5.1	34.92±5.2
Humidity (%)	27.71±14.2	42.57±13.6	44.35±14.9	35.57±18.2
Wind speed (Km/h)	14.23±4.2	8.15±3.5	10±6.6	12.28±3.8

Table 7: Daily average meteorological data during 2nd lockdown

Meteorological data during 2nd lockdown in the year 2021				
2nd Lockdown 2021	**Phase 1**	**Phase 2**	**Phase 3**	**Phase 4**
	April 20–April 30	May 1–May 10	May 11–August 14	August 15–August 22
Temperature (°C)	34.18±2.8	31.7±3.3	30.65±3.4	28.37±2.4
Humidity (%)	27.90±9.8	48.7±9.8	73.97±14.7	81.25±4.8
Wind speed (Km/h)	10.18±4.04	8.2±2.9	9.73±4.05	9.25±1.3

Figure 3: Location of the selected city (map not to scale) Adapted from ref [12].

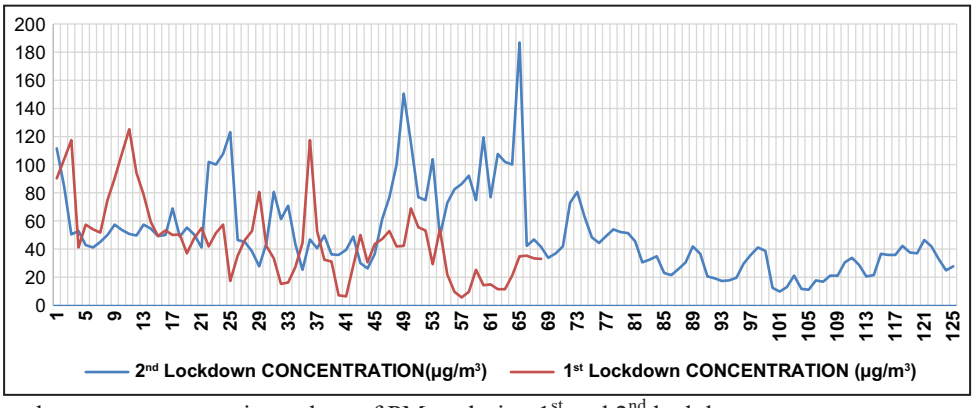

Figure 4: Comparison between concentration values of PM $_{2.5}$ during 1st and 2nd lockdown.

atmosphere. Though the NO_2 AQI readings dropped during both lockdowns, the second lockdown saw a steady fall in the values for the past 2 months, as it coincided with monsoon months (Figure 9). With the help of Figure 5, the regression trends during 1st and 2nd lockdown can be analyzed.

3.4. Sulfur Dioxide (SO_2) Trends During 1st and 2nd Lockdown

With the help of Figure 6 variations in the AQI of SO_2 can be comprehended. It's worth noting that the SO2 AQI did not exceed 3 during the first lockdown. The probable reasons could be the closure of many industries and decreased demands of fossil fuels. The highest

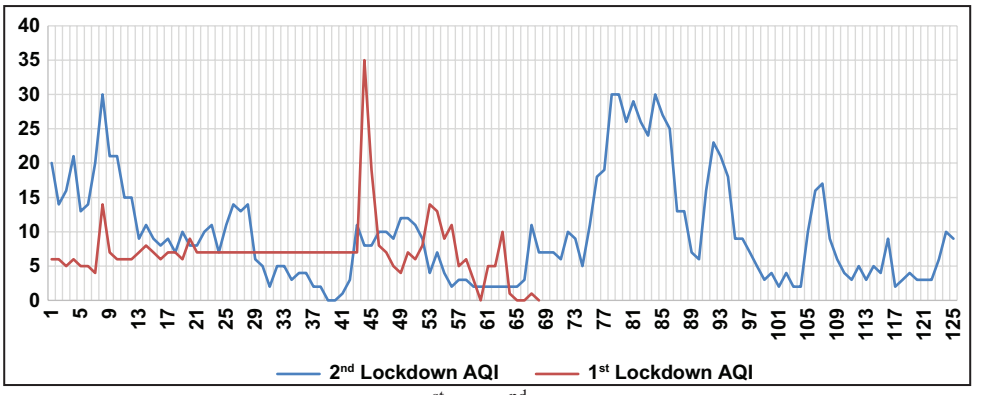

Figure 5: Comparison between AQI values of NO_2 during 1st and 2nd lockdown.

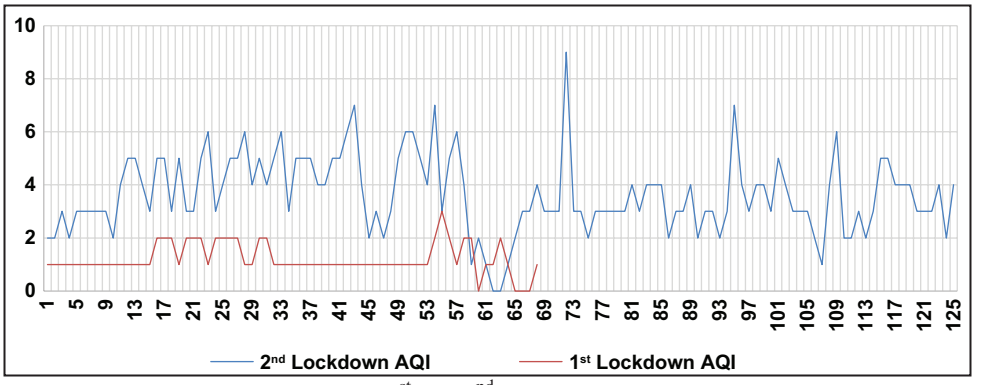

Figure 6: Comparison between AQI values SO_2 during 1st and 2nd lockdown.

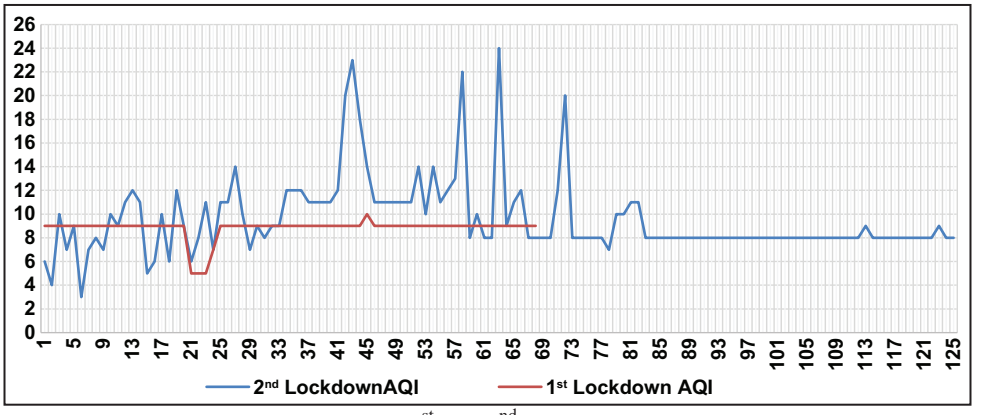

Figure 7: Comparison between AQI values of CO during 1st and 2nd lockdown.

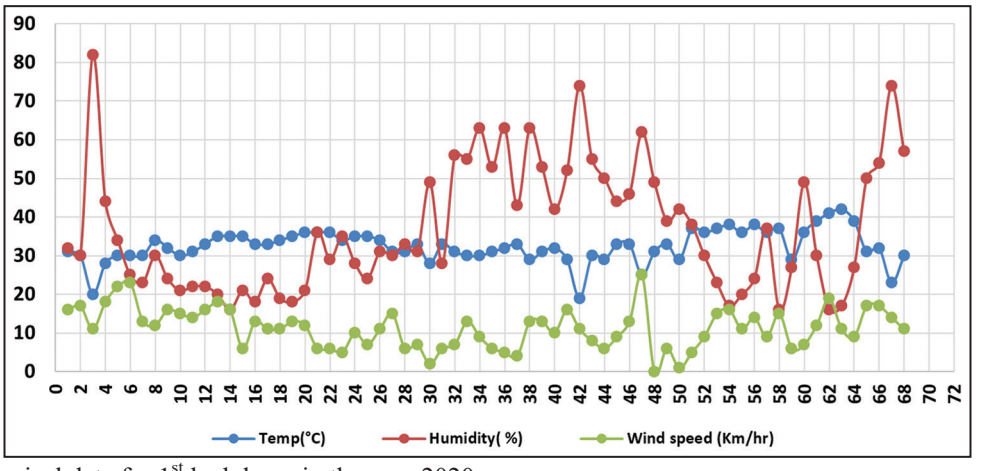

Figure 8: Meteorological data for 1st lockdown in the year 2020.

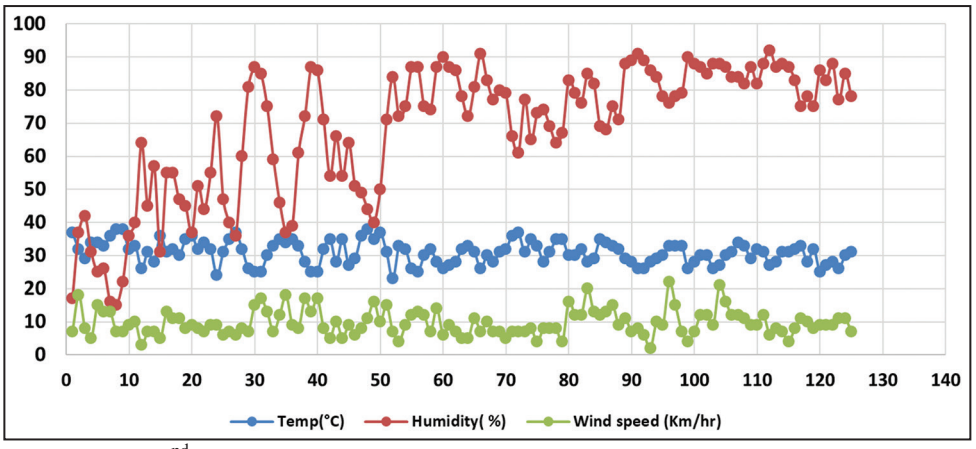

Figure 9: Meteorological data for 2nd lockdown in the year 2021.

reported value of SO_2 during the 2nd lockdown was 9, when numerous industries restarted operations, but values decreased later in the lockdown due to the onset of monsoon in India (Figure 9).

3.5. Carbon Monoxide (CO) Trends During 1st and 2nd Lockdown

Figure 7 showcases the significant trend of AQI values of CO during both lockdowns. As it is evident from the graph, CO levels were lower during the first lockdown than during the second lockdown because vehicular movement was strictly restricted during the first nation-wide lockdown, whereas vehicular movement was allowed for a limited time frame but never completely stopped during the second state-wide lockdown. The second lockdown also had the highest number of corona deaths, 374 deaths in just 24 h. Corona patients' bodies were set on fire in the open air, causing a rise in Carbon monoxide levels in the neighborhood. Rainfall only came later in the second lockdown, assisting in the reduction of AQI values (Figure 9). The highest and lowest AQI values of CO during 1st lockdown were 10 and 5, respectively, and the highest and lowest AQI value of CO during 2nd lockdown were 20 and 5, respectively.

With the help of Figures 8 and 9, the values of temperature (°C), humidity (%), and wind speed (Km/h) during 1st and 2nd lockdown can be observed and analyzed. The meteorological data help in the interpretation of the variation trends of various pollutants giving significant reasons.

4. CONCLUSION

There can be no doubt that the lockdown period assisted Mother Nature in healing and repairing herself [14]. Restrictions on numerous human activities aided in improving the quality of the ambient air. Both the nation-wide and state-wide lockdowns played a role in lowering pollution levels in the air. Despite the fact that the second lockdown had more relaxations than the first, there was still a decrease in air pollutant measurements [15]. The terrifying second wave of COVID-19 in India, when infection and death rates were rising at an alarming rate, people were afraid and curtailed their travels to avoid coronavirus, could be one of the explanations. Which lockdown was more impactful in improving air pollution? Initially the dropping of concentration values of $PM_{2.5}$ from 186.6 to 41.5 $\mu g/m^3$ and AQI values of NO_2, (from 35 to 0) SO_2, (from 3 to 0) and CO (from 10 to 5) can be totally attributed to the strict lockdown across the country as a result of which many anthropogenic activities and vehicular mobility were restricted. The 2nd lockdown also recorded drop in the concentration values of $PM_{2.5}$ (125.2–11.5), drop in the AQI values of gaseous pollutants, that is, for NO_2 (from 30 to 2), for SO_2 (from 9 to 1), and for CO (from 20 to 5). Although both lockdowns helped to improve ambient air quality in Lucknow's Lalbagh, the second lockdown had several advantages, such as the fact that nature had already recovered from the first lockdown, and the later portion of the second lockdown coincided with India's monsoon season. As a result, both stages of the lockdown helped to enhance air quality during their different phases, but the second lockdown, by taking advantage of its opportunities, helped a little more!

5. ACKNOWLEDGMENTS

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Bibliographical Sketch

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