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Original Article

Changes in Atmospheric Air Quality in the Wake of a Lockdown Related to Covid – 19 in the Capital City of Southern State of India, Kerala – Thiruvananthapuram

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Abstract *- The impact of the COVID-19 Lockdown on SO_2, O_3, CO, particulate matters (PM_{10} and $PM_{2.5}$), NO_2, NO_X, and NO over the capital city of Kerala (in India), Thiruvananthapuram, on Pre-lockdown phase, phase 1 of Lockdown, phase 2 of Lockdown and triple lockdown periods in 2019, 2020, and 2021 are studied. Because anthropogenic activities were reduced during the lockdown and air quality improved. AQI reduced by 25% and 26%, respectively, compared to the 2019 average value of AQI. The lower the AQI value indicates the influence of the Covid 19 lockdown on air quality.*

Keywords *- COVID-19, Lockdown, Thiruvananthapuram, Air pollutants, Air quality*

1. Introduction

One of the most pressing concerns in the twenty-first century is air pollution. The World health organization (WHO) claims, "The modification of natural characteristics of the atmosphere by any chemical, physical or biological agents is called air pollution" [1]. Anthropogenic activities, including agricultural burning, industrial operations, pesticide usage, plastic burning, forest fires, and gases released by motor vehicles, contribute to the rising rate of pollutants in the atmosphere.SO_2, O_3, CO, NO_2, NO_X, NO, and particulate matters (PM_{10} and $PM_{2.5}$) are principal pollutants that cause health problems [2]. According to WHO, "Every year, more than 7,000,000 people die due to air pollution, making it a severe health hazard. The largest anthropogenic sources of particulate matter include emissions of gases from cars and industry, building construction, and fuel combustion" [3].

In December 2019, In Wuhan, China, the novel SARS-CoV-2 coronavirus disease was initially found. [4]. On 2020 January 30, it was first reported in Kerala, a southern state of India. To take a major step toward taming the dread march of deadly coronavirus, the Indian government announced a national lockdown for 21 days from March 25. After that, the state government of Kerala declared a 'triple' lockdown. Thiruvananthapuram is the capital of Kerala, India's southernmost state. Triple Lockdown is a 3 layered targeted method to halt the coronavirus from spreading. The regions under triple Lockdown were under police monitoring. After announcing the Lockdown, educational institutes, most industries, shops, and flight services remained closed, reduced the number of vehicles on the road, and people started to stay home. This means anthropogenic sources of aerosols' emissions were less than in previous years. The Variation of SO_2, O_3, CO, particulate matters, NO_2, NO_X, and NO during the Pre-lockdown phase, phase 1 of Lockdown, phase 2 of Lockdown, and triple lockdown periods 2019, 2020, and 2021 are investigated. This research aims to see how the Covid-19 Lockdown affects the atmosphere over Thiruvananthapuram. [5].

2. Literature review

In December 2019, the first human instance of COVID-19 was found, and the WHO proclaimed COVID-19 a pandemic on March 11, 2020. To prevent the virus from spreading further, the Indian government enforced a lockdown beginning March 25, 2020. It has significantly affected economic activities worldwide [6]. Gope et al., 2021 [6] were researched, The influence of the covid -19 pandemic on air pollution in India's four major cities: Kolkata, Hyderabad, Mumbai, and New Delhi.

In this study, they determined that Except for SO_2 and O_3, most air pollutants and AQI decreased throughout the lockdown period. During the Lockdown, the average AQI in New Delhi, Kolkata, Mumbai, and Hyderabad plummeted by 31%, 73.5 percent, 31%, and 19.5 percent, respectively. Thomas et al., 2020 [7], Kumari & Toshniwal, 2020 [8], Resmi et al., 2020 [9], and Sahoo et al., 2020 [10] also studied the influence of COVID-19 on air quality in several Indian cities. In these studies, the different parameters like CO, Sulphur dioxide (SO_2), NO_2, NO_X, NO, O_3 (ozone), and particulate matters (PM_{10} and $PM_{2.5}$) have been taken into account for determining the Air Quality Index. $PM_{2.5}$ and AQI (Air Quality Index) levels have dropped significantly in most Indian cities.

According to Singh & Chauhan, 2020 [11], studies on variations in tropospheric NO_2 concentration over Delhi, Mumbai, Hyderabad, Kolkata, and Chennai. In contrast to 2019, they saw a considerable decrease in tropospheric NO_2 concentrations throughout the lockout period in 2020. A similar observation can be seen in Ravindra et al. 2021 [12] research studies on the same Indian megacities. Not just in India but also in numerous other nations, the COVID-19 epidemic improved air quality. To control the transmission of the virus of a novel coronavirus, most countries restricted road transportation and human activities. Chinese government restricted road transportation and anthropogenic activities from late January to early February 2020. During the lockdown phase, economic activities decreased dramatically. A similar case can be seen in Iran (Broomandi et al., 2020) [13], Malaysia [14], Kazakhstan [17], Barcelona of, Spain, Ecuador [16], etc.

Kumari & Toshniwal, 2020 [8] analyzed ground-based data from 12 major cities worldwide and determined that particulate matter and NO_2 concentrations were lowered by 20–34 %, 24–47 %, and 32–64 %, respectively. Similarly, a negative correlation was observed between NO and O_3. The concentration of O_3 increased with the decreasing trend of NO concentration in the atmosphere. In Resmi et al. 2020 [9] research over Kannur, India, a similar observation can be seen. "The Surface O_3 production rose over Kannur during triple-lockdown days, whereas CO (67 %), VOCs (61 %), SO_2 (62 %), and NH_3 (16 %) concentrations all dropped significantly from pre-lockdown to triple-lockdown days" [9]. All of these researches on COVID 19 on air quality point to the fact that during lockdown times, the quality of air in the environment improves across the world.

3. Methodology

3.1 Site Description

According to Census Statistics of India - 2011, Thiruvananthapuram is one of the major cities in south India, with a population density of 1,509 inhabitants per square kilometer (3,910/square mi) [18]. It is located on seven hills near the coastline at 8.5°N and 76.9°E on the west coast [19]. Thiruvananthapuram also shares a border with the

Fig. 1 (a) Thiruvananthapuram, Kerala, India, as shown on a map, (b) Aerial view of Plammoodu [20].

The neighboring state of Tamil Nādu and having a long coastal belt with unique features stretching for 78 km in its entire western border makes it more vulnerable to a pandemic than any other district of Kerala.

On January 30, 2020, Kerala reported the first corona virus-positive case in India, and After that, the first incidence of COVID-19 in the Thiruvananthapuram district was reported on 13th March 2020 [21]. Thiruvananthapuram is one of India's major tourism, IT, educational, and cultural hubs. It is also known as the "Evergreen City of India ."The aerial view of our research site and surroundings are shown in Fig. 1(a).

3.2. Data Collection

The central pollution control board constructed continuous air quality monitoring stations in 134 cities throughout India's 23 states. It connected them to a web-based system to measure real-time ambient air quality [9]. This web-based system is designed to provide Real-time data on AQI by using an AQI calculator, which is available for the public on the " https://app.cpcbccr.com/AQI_India/ " website [22]. We collected the CSV formatted data from this website for this study. On these stations, all of the criteria may not be considered simultaneously. The total value of AQI can be determined only if the data for at least three pollutants are known, and from that, one should be the values of particular matters [23].

3.3. Data Preprocessing

According to Ebin Antony et al. (2021), any data collected using electronic sensors is vulnerable to mistakes. These errors might occur during the data taking, recording, or transmission stages. In particular, electronic sensor-based data is heavily used by researchers in atmospheric science and environmental science. Data collected over time by electronic sensors installed in the field may be difficult to spot defects or inaccuracies. Missing values, noise or outliers, and seasonal changes are examples of errors or glitches. If these flaws are not corrected, unexpected differences in the results may occur. Standard data cleaning processes are used to overcome this challenge, such as eliminating outliers or noisy data and managing missing numbers [24].

Table 1. CPCB provided Breakpoint concentrations of different pollutants for AQI calculation [25]

AQI Category (Range)	PM_{10} (24hr)	$PM_{2.5}$ (24hr)	NO_2 (24hr)	O_3 (8hr)	CO (8hr)	SO_2 (24hr)	NH_3 (24hr)	Pb (24hr)
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5-1.0
Moderately (101-200)	101-250	61-90	81-180	101-168	2.1-10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10.1-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748	17-34	801-1600	1200-1800	3.1-3.5
Severe (401-500)	430+	250+	400+	748+	34+	1600+	1800+	3.5+

3.4 AQI (Air Quality Index) calculation

It is defined as: “an index that measures the quality of the air we breathe over a given period” [23]. By using the 24-hourly daily average concentration of individual pollutants (Sulphur dioxide (SO_2), O_3, CO, NO_2, NO_X, NO, and particulate matters) and the range of health breakpoint concentration in our monitoring location, we can easily find out the AQI. AQI is very helpful in understanding how polluted the place we live is, and thereby we can provide advice to improve air quality.

The AQI is split into six categories based on the ambient concentration of pollutants in the air and their impact on human health. According to CPCB (2014) National air quality index report, they are Good (0-50), Satisfactory (51-100), moderately polluted (101-200), Poor (201-300), Very Poor (301-400), and Severe (>400)” [25]. Table 1 shows the breakpoint concentrations of several contaminants reported by CPCB.

4. Results & Discussion

Concentration in this experiment, different data science tools and techniques such as outlier removal and missing value replacement approaches, and smoothening are used to generate the cleaned data. The study period was divided into four phases to assess better the impact of covid – 19 lockdowns on various pollutants and air quality in Thiruvananthapuram.

- Before Lockdown (1st February to 25th March)Phase 1 of Lockdown (25th March to 15th April)
- Phase 2 of Lockdown (16th April to 15th May) and
- Triple Lockdown Phase (16th May to 30th May)

The variations of SO_2, NH_3, PM_{10}, $PM_{2.5}$, NO_2, O_3, and CO in 2019, 2020, and 2021 were considered for the analysis.

4.1. Impact of covid - 19 lockdowns on NO_2 and CO concentration

When comparing the values of NO_2, at the beginning of February, a comparatively larger value of NO_2 was observed. On 28th February, the maximum value of NO2 was observed in 2020, and after 24th march decrease in the values of NO_2 was observed. The largest producers of NO_2 are commercial manufacturing companies, food-producing industries, fossil fuel combustion, etc.

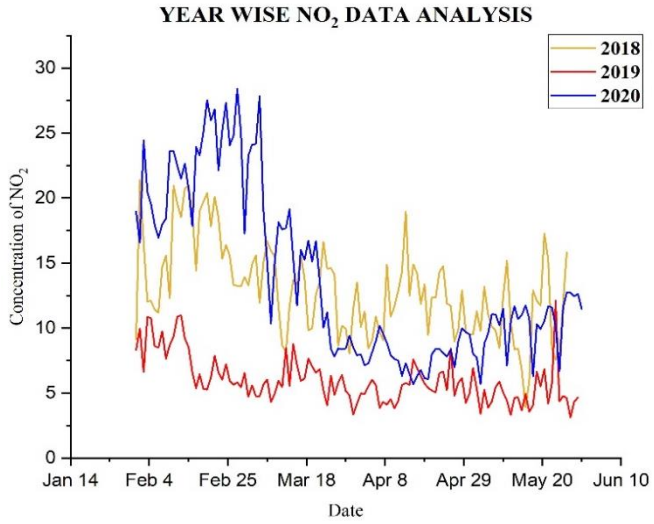

Fig. 2 Variation of NO_2 in 2018,2019 and 2020 in Thiruvananthapuram

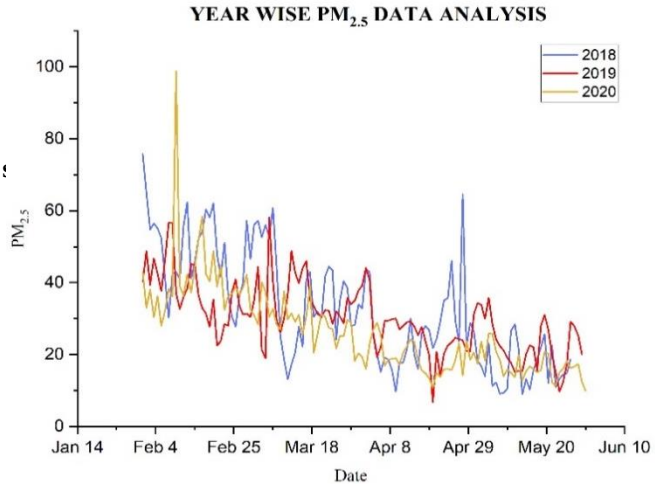

Fig. 3 Variation of CO in 2018,2019 and 2020 at Thiruvananthapuram

The graph showing the variation of NO_2 in 2018,2019, and 2020 is shown in Figure 2. Similarly, the maximum and least concentration of CO was observed on 5th March 2020(2.17 ppbv) and 7th April 2020 (0.32 ppbv). It was 0.46ppbv (on April 8, 2020) and 0.43ppbv (on May 18, 2020) throughout lockdown phases I, II, and triple, respectively. Following Lockdown, the CO content was determined to be substantially lower. The graph showing the variation of CO in 2018,2019, and 2020 is shown in Fig. 3.

Compared with 2018 and 2019, the least concentration of CO was observed after 30th March 2020. The lockdown period had the lowest CO levels of the three years. The emissions of fossil fuels from cars and factories are the primary sources of CO and NO_2. After announcing the Lockdown, people started to stay home, most of the industries and public road-train services remained closed, and the number of vehicles used decreased. As a result, it might impact the huge decline in CO and NO_2 concentrations.

4.2. Impact of covid 19 lockdowns on particulate matters values

On 28th April 2018, the $PM_{2.5}$ value showed the highest value among the 3 years in our study period; on the same date in 2020, the value of $PM_{2.5}$ observed was 14.13 micrograms/cubic meter. The least value of $PM_{2.5}$ was observed in the triple lockdown period on 23rd May 2020 (11.41 µg/m^3). Similarly, the maximum value of PM_{10} was observed Before Lockdown, 1st phase of Lockdown, 2nd phase of Lockdown, and triple Lockdown are on 1st March (123.28 µg/m^3), 14th April (52.42 µg/m^3), and 20th May (44.22 µg/m^3) respectively.

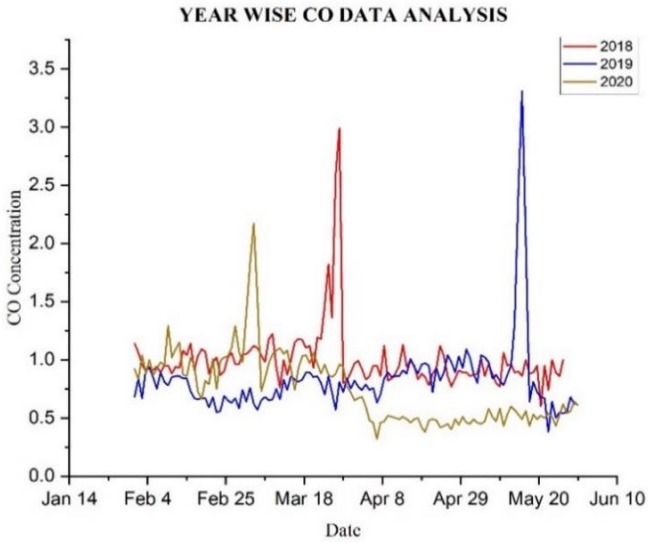

Fig. 4 Variation of $PM_{2.5}$ in 2018, 2019, and 2020 at Thiruvananthapuram

And the least value of PM_{10} was observed Before Lockdown, 1st phase of Lockdown, 2nd phase of Lockdown, and triple Lockdown are on 4th March(50.14 µg/m^3),20th of April (20.13 µg/m^3), and 23rd May(30.8 µg/m^3) respectively. The graph showing the variation of PM_{10} and $PM_{2.5}$ in 2018,2019, and 2020 is shown in Figure 4 and Figure 5, respectively.

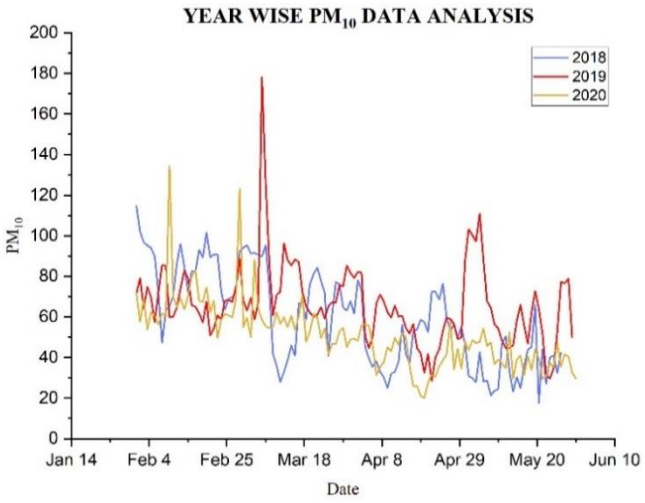

Fig. 5 Variation of PM_{10} in 2018,2019 and 2020 at Thiruvananthapuram

The particulate matter values were significantly reduced throughout the lockdown-triple lockdown period. The primary sources of particulate matter diameter of 10 microns or less (PM_{10}) include pollen, sea salt, industrial sources, natural dust, etc. [26]. Similarly, forest fires, car engines, and power plants are the major sources of particulate matter diameter of 2.5 or less ($PM_{2.5}$) [26]. During the lockdown time, the reduction in anthropogenic activity may impact the number of particulate matters in the atmosphere.

4.3. Impact of lockdowns on the concentration of SO_2, NH_3

Ammonia (NH_3) is produced in the atmosphere by agricultural and human activities and industrial and automobile emissions. Particulate matter generation (Behera et al., 2013), degradation invisibility, and public health are all influenced by NH_3. Particulate matter generation (Behera et al., 2013), degradation invisibility, and public health are all influenced by NH_3.

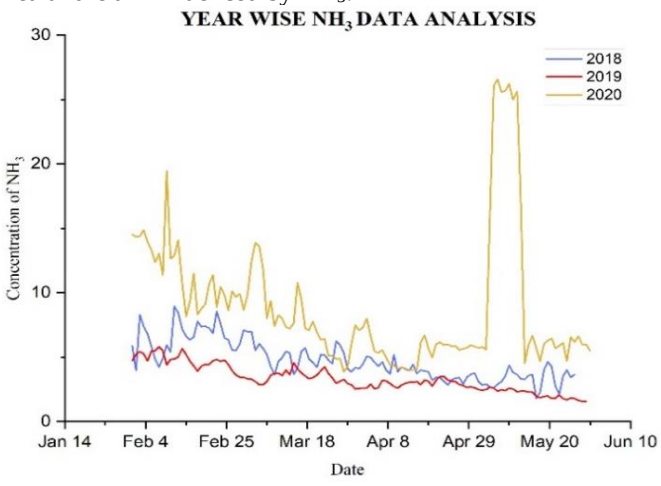

Fig. 6 Variation of NH_3 in 2018, 2019, and 2020 at Thiruvananthapuram

The maximum concentration of NH_3 was observed before the lockdown phase, the first lockdown phase, the second lockdown phase, and triple lockdown periods are on 16th March (8.75 µg/m^3),10th April (5.76 µg/m^3), and 16th May (6.17 µg/m^3) respectively. Before the lockdown phase, the first lockdown phase, the second lockdown phase, and triple lockdown periods, the lowest value of NH_3 was reported on March 5th (3.82 µg/m^3), April 7th (4.24 µg/m^3), and May 21st (5.15 µg/m^3), respectively. Figures 6 and 7 depict the variance of NH_3 and SO_2 in 2018, 2019, and 2020, respectively.

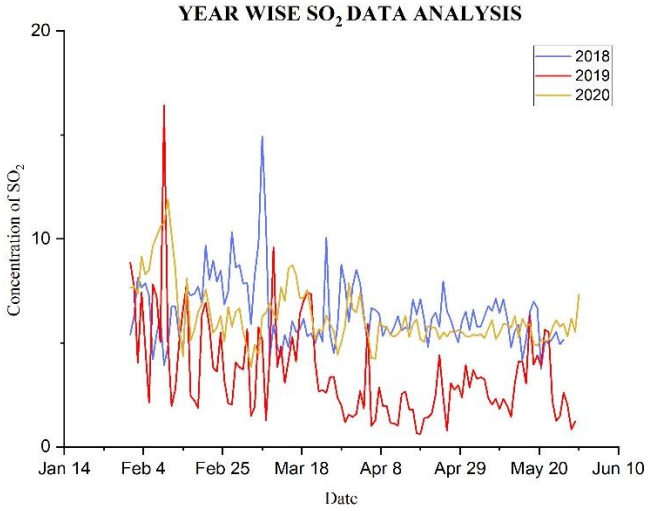

Fig. 7 Variation of SO_2 in 2018, 2019, and 2020 at Thiruvananthapuram

SO_2 is another important parameter in our study. SO_2 is one of the major components of acid rain, and it may affect the respiratory system and irritate the respiratory tract and eyes. "The major sources of SO_2 are primarily the burning of Sulphur rich fossil fuels like coal, oil, and petroleum" [28]. In comparison with 2019, a larger concentration of SO_2 was observed in 2020. but in comparison with 2018, a significant decrease in the concentration can be observed.

4.4. Impact of lockdowns on the concentration of O_3

"The primary O_3 producers are Fossil fuel combustion, gas emissions from vehicles, power plants, oil refineries, and Photochemical reactions Between VOCs and oxides of Nitrogen in the presence of sunlight, etc." [29]. In comparison with 2018 and 2019, the ozone in the atmosphere shows lower values, but an irregular variation was observed in the lockdown period. The lowest concentration of O_3 was observed on 26th May 2020. The graph showing the variation of O_3 in 2018, 2019, and 2020 is shown in Figure 8.

In comparing the average values of AQI in the three years in the study period, AQI was reduced by 32% and 17% compared to the values in 2019 and 2018, respectively, in the phase I lockdown period. Similarly, in the phase II period of lockdown and triple lockdown stages, AQI was reduced by

25% and 26%, respectively, compared to the 2019 average value of AQI. Similarly, in the phase II period of lockdown and triple lockdown stages, AQI was reduced by 25% and 26%, respectively, compared to the 2019 average value of AQI.

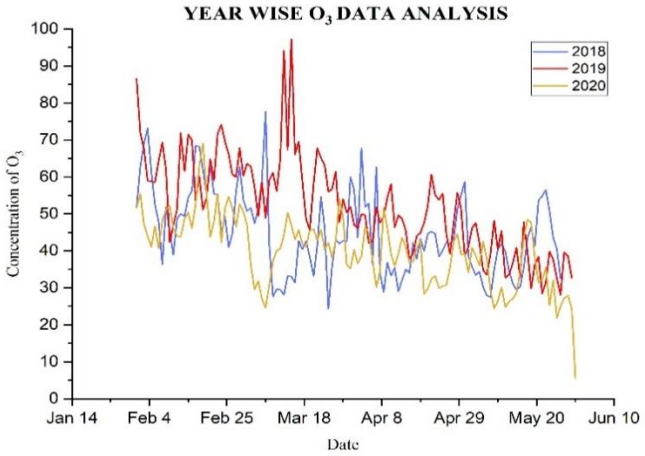

Fig. 8 Variation of O_3 in 2018,2019 and 2020 at Thiruvananthapuram

4.5. Impact of lockdowns on the concentration of AQI

Compared with 2018 and 2019, The AQI value in Thiruvananthapuram shows a significant decrease in 2020. at the beginning of march month of 2020, the AQI values were higher, and after that, from 21st march 2020 onwards, AQI values started to decrease. In lockdown phase I, the lowest value of AQI was observed on 31st March 2020 (52). Similarly, in the second phase of Lockdown, and triple lockdown phase, the lowest value of AQI was observed on 22nd April 2020 (46) and 25th May 2020, respectively. The graph showing AQI variation in 2018,2019, and 2020 is shown in Fig. 9. Before the lockdown phase, the first phase of Lockdown, the second phase of Lockdown, and triple lockdown periods, the maximum value of the Air quality index observed

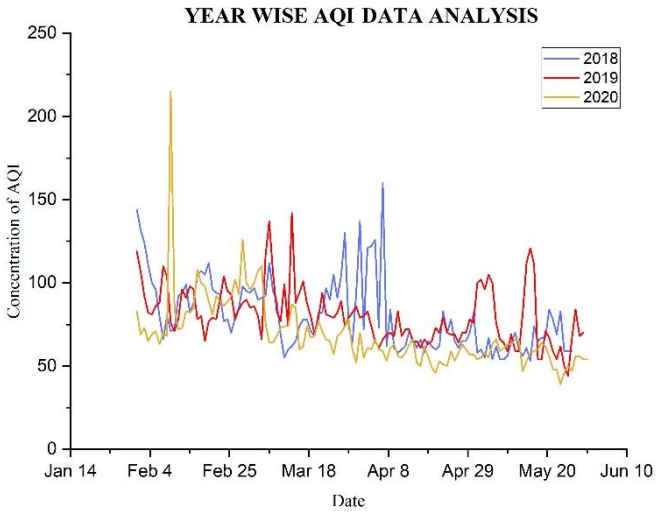

Fig. 9 Variation of AQI in 2018,2019 and 2020 at Thiruvananthapuram

is, the maximum value of the Air quality index observed is 126 (1st March), 78 (29th March), and 62 (20th May), respectively. At the beginning of march month, comparatively larger values of AQI were observed, and after that, AQI values decreased significantly during the lockdown period. The lower value of AQI indicates better quality of air. The air pollution was reduced in the lockdown period due to the reduction in anthropogenic activities. It may help to prevent the covid virus spread in Thiruvananthapuram city.

In short, the concentration of SO_2 in 2020 lockdown phases I and II decreased by 11% and 10%, respectively, compared to the values in 2018. But comparing with the values in the triple lockdown period and values in 2019, a rise in the concentration of SO_2 was observed. Compared to typical SO_2 readings in 2019, the average value of SO_2 rose 72%, 168 %, and 131 % in the triple lockdown phase, the first phase of Lockdown, and the second phase of Lockdown, respectively.

Similarly, the concentration of NH_3 in 2020 lockdown phases I and II increased by 83% and 303%, respectively, compared to the values in 2019. However, when comparing measurements from the triple lockdown period to values from 2019, a rise in NH_3 concentration was observed. The average value of NH_3 increased 78%, 16%, and 230 % in the triple lockdown period, phase I of Lockdown, and phase II of Lockdown, respectively, compared to the average values of NH_3 in 2018.

For NO_2, in the first phase of the Lockdown in 2020, the concentration decreased by 53.11 %, compared to the average values before the lockdown period. And after that, in the first phase of Lockdown, the values decreased by 49.9 % and 37.72 %, in the lockdown phase II and triple lockdown period, respectively. In the first phase of Lockdown, the concentration on average of O_3 was increased by 0.4 % compared to the average values in the prior lockdown phase. And after that, in the first phase of Lockdown, the values decreased by 20.28 % and 24.05 %, in the second phase of Lockdown and triple lockdown period, respectively.

At the same time, other parameters like CO, $PM_{2.5}$, PM_{10}, and AQI show a drastic decrease in concentration after the Lockdown was observed. The concentration of CO in 2020 lockdown phases I and II decreased by 18 % and 23%, respectively, compared to the values in 2019. When comparing the readings from the triple lockdown period to the values from 2019, a rise in CO concentration was seen. Compared to the average CO values in 2018, the average CO values in triple Lockdown, the first phase of Lockdown, and the second phase of Lockdown reduced by 45 %, 47 %, and 41 %, respectively. Compared to the average values before the lockdown period, concentration on average of $PM_{2.5}$ was reduced by 40% in phase I of Lockdown. And after that, in phase I, the values decreased by 78 % and 94 %,

respectively, in the lockdown phase II and triple lockdown period. In PM_{10}, the average concentration of $PM_{2.5}$ in the first phase of Lockdown was reduced by 40% compared to the average values before the lockdown period. And after that, in phase I, the values decreased by 78 % and 94 %, respectively, in the lockdown phase II and triple lockdown period.

On comparing the average values of AQI in the 3 years in the study period, AQI was reduced by 32% and 17% compared to the values in 2019 and 2018, respectively, in the first phase of Lockdown. Similarly, in the second phase of Lockdown and triple Lockdown stages, AQI was reduced by 25% and 26%, respectively, compared to the 2019 average value of AQI. The lower value of AQI indicates better quality of air.

5. Conclusion

Using the obtained data, the fluctuations in PM_{10}, $PM_{2.5}$, NO_2, SO_2, NH_3, O_3, and CO concentrations in the capital of the southern Indian state of Kerala, Thiruvananthapuram, were analyzed in the years 2019, 2020, and 2021.AQI reduced by 25% and 26%, respectively, compared to the 2019 average value of AQI. The lower value of AQI indicates better air quality, which shows the impact of covid 19 lockdown on air quality. Other measures such as CO, $PM_{2.5}$, PM_{10}, and AQI also show a considerable reduction in concentration after the lockdown period.

But, at the same time, the concentration of NH_3 in 2020 lockdown phases I and II increased by 83% and 303%, respectively, compared to the values in 2019. In phase I of Lockdown, the average concentration of O_3 was increased by 0.4 % compared to the average values in the prior lockdown period. And after that, in phase I, the values decreased by 20.28 % and 24.05 %, in the lockdown phase II and triple lockdown period, respectively. In short, due to the reduction in human activity, air quality increased during the lockdown time. It may prevent the covid virus from spreading in Thiruvananthapuram city.

Acknowledgments

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