ASSESSMENT OF AIR QUALITY IN INDO GANGETIC PLAIN DURING LOCKDOWN PHASES IN 2020

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

MASTERS OF TECHNOLOGY

IN

ENVIRONMENTAL ENGINEERING

Submitted by

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2K19/ENE/18

Under the supervision of

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ENVIRONMENTAL ENEGINEERING

DELHITECHNOLOGICAL UNIVERSITY

(Formerly, Delhi College of Engineering) Bawana Road, Delhi-110042 JUNE, 2021

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I AKASIIMA LORNA KAIJUKA, Roll No.2K19/ENE/018of MTech (Department of Environmental Engineering), declare that this project Dissertation with title" ASSESSMENT OF AIR QUALITY IN INDO GANGETIC PLAIN DURING LOCKDOWN PHASES IN 2020" that I have submitted to the Department of Environmental Engineering, at Delhi Technological University, Delhi in partial fulfilment that is required of me to be awarded degree of Master of Technology in Environmental Engineering. This thesis is original, any material copied is cited properly. This work is not previously used to acquire any award, like Degree, Diploma Associateship, fellowship or any other award.

PLACE: DELHI AKASIIMA LORNA KAIJUKA

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PLACE: DELHI

MRS LOVLEEN GUPTA

SUPERVISOR

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I can't for leave without thanking my friend and family who has supported both emotionally and financially during the process of doing this thesis.

I would like to also convey my deepest gratitude to my scholarship scheme, INDIAN COUNCIL FOR CULTURAL RELATIONS to grant me a scholarship to come and study from such an interesting highly ranked country.

Above all I owe it all to my Almighty God Through Jesus Christ for giving me wisdom, protection, health, life and strength to undertake this Research task and enabling me to completion.

I submit

AKASIIMA LORNA KAIJUKA

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ABSTRACT

Analyzing the trend of air quality from previous years to date, helps policy makers and community to know how to deal with air pollution. The World Health Organization declared COVID-19 as pandemic in early March. India announced Janata curfew which means peoples curfew on Sunday 22, March 2020. From 22nd March 2020 throughout all the lockdown phases, the air quality was observed and different air pollutants decreased in concentration apart from Ozone. This study focuses on concentrations of five pollutants $PM_{2.5}$, NO_2, NO, ozone and SO_2 from January, 2016 to December, 2020. The study is done for 7 cities in the Indo Gangetic Plain (IGP), these include Delhi (capital city of India), Rohtak (city in state of Haryana and upwind of Delhi), Faridabad (most populated city in Haryana and downwind of Delhi), Kanpur (industrial city in state of Uttar Pradesh), Agra (city in Uttar Pradesh with high tourism), Varanasi (holy city in Uttar Pradesh known for high number of funeral pyres) and Lucknow (capital city of Uttar Pradesh). The concentration of different air pollutants has been decreasing from 2016 for all cities, this shows the effect of multiple control measures put in place by the Indian Government. The trend greatly changed in the year 2020 which also shows the effect of different lockdown phases to the air quality. Using spatial analysis, its clearly seen that $PM_{2.5}$ is the one that mostly pollutes the air mostly the during winter season. However much there was lockdown in 2020 from the second quarter of the year. But in comparison with the same periods in 2019, it’s also seen that there is great influence caused by meteorological factors, as it is seen that during winter the air quality index of $PM_{2.5}$ is poor.

CONTENTS

PROBLEM STATEMENT

There has an outcry from public suffering from many diseases that cause air pollution. Also, many studies in the year of 2020, were talking about how air pollution has reduced due to lockdown and studies were suggesting that lockdown can be way to control air pollution. For these reasons I picked interest to find out the trend of air quality status for past five years and also compare the air quality status of different grouped lockdown phases period with the same period in the year 2020.

OBJECTIVES

1. To determine the mean annual concentration of five air pollutant that is NO_2, Ozone, $P.M_{2.5}$ NO, SO_2 for years 2016 to 2020 using bar graph.
2. To determine the daily mean concentration of the parameter given above using time series analysis for seven cities in Indo- Gangetic Plain.
3. To the quality of air during different lockdown phase groups using air quality index and spatial analysis.

CHAPTER ONE

INTRODUCTION

Particulate matter is the pollutant that mostly affects India. The concentration of $PM_{2.5}$ exceeds the required limit according to (NAAQS)National Ambient Air Quality Standards. It is believed the many health complication in India are caused by unfavorable air pollution. (Heal et al., 2012; Dholakia et al., 2013). These include, shortness of breath, chronic respiratory disorders, pneumonia, acute asthma etc. And due to covid-19 lockdown, studies have shown improvement in air quality.

The primary sources of air pollution in India are found to be as vehicular emissions, industrial emissions, coal combustion, biomass burning, road dust, and refuse burning(Sharma et al., 2020). Delhi as the capital city of India, surrounded by Uttar Pradesh and Haryana states. The National Clean Air Program (NCAP), to control the poor air quality across the nation, it started a five-year plan in the year 2019 to reduce the concentration of particulate Matter by 30%. (MoEFC, 2019).

Janata curfew became phase 1 of the lockdown of India. Phase 2 of lockdown was imposed on the whole country, starting on mid night of 24 March 2020 to 14th, April 2020. Phase 3 of lock down was imposed from 15th April to 3rd May 2020. Phase 4; On 1 May, the Government of India (GoI) further extended the lockdown period to two weeks beyond 4th May, with some relaxations. The country was split into 3 zones: red zones (130 districts), orange zones (284 districts) and green zones (319 districts). Red zones were those with high coronavirus cases and a high doubling rate, orange zones were those with comparatively fewer cases than red zone and green zones were those ones without any cases in the past 21 days. Normal movement was permitted in green zones with buses limited to 50 percent capacity. Orange zones allowed only private and hired vehicles but no public transportation. The red zone would remain under lockdown. The zone classification was revised once a week.
The objective of this study is to analyze and assess the air quality status for 7 cities (Kanpur, Faridabad, Varanasi, Agra, Lucknow, Rohtak, Delhi) for past five years. and assessing and comparing air quality during 2020 lockdown phases with the same period in 2019.

Air quality data is taken from Central Pollution Control Board, (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data).

Agra; There is a UNESCO World Heritage site on the banks of Yamuna where Taj Mahal is known. This brings tourists over 8 million year after year. Agra depends on small scale industry of handicrafts, leather goods iron foundries, tourism and agriculture. These activities has led to increase of poor air quality in Agra city.(Guttikunda et al., 2019)

Varanasi; This was known as Banaras. It is a city where pilgrimage as well as tourism are mostly done in India. Varanasi is found in the state of Uttar Pradesh and located around river Ganges (approximately 3 million Indians and 200,000 foreigners). Due to these activities that take place in this city, solid waste management becomes a problem. This means the waste is burnt, deposited into landfills and some thrown into the river, which pollutes air. The city is also known for making other handcrafts like fabrics of muslin and silk, perfumes, ivory works, sculpture, diesel locomotive works and many others. (Guttikunda et al., 2019). **Rohtak;** the district administrative headquarters and the city are located in Haryana. Rohtak is also located in the National Capital Region and also in the Indo Gangetic Plain. This contributes to the growing of its economy as it easily acquires loans for infrastructure cheaply the planning Boards. Rohtak takes the sixth position of the most populated city in Haryana according to the census done in 2011 with 374,292 people. It is noticed that Haryana state Industrial and infrastructure Development Corporation developed an industrial Township like Suzuki Motorcycle, Asian Paints. (Guttikunda et al., 2019). **Faridabad** is located in Haryana state and is the most populated city in Haryana. the most populous city in the Indian state of Haryana. It is also the most industrious city. It is among the main satellite cities in the state of Delhi. The production of henna which is a product of agriculture makes Faridabad famous. The industrial products are refrigerators, shoes, tyres, tractors, motorcycles and many others. World Health Organisation ranked Faridabad as the second highly populated city in the world. This was done in the year 2018. (Guttikunda et al., 2019). According to Mr. Guttikunda's study, it is said that on the Indo-Gangetic Plain, **Kanpur** is one of the largest industrial towns in North India and the largest city in in the state of Uttar Pradesh. Kanpur supports the largest textile and leather processing sectors in the region.(Guttikunda et al., 2019). Kanpur tried constructing a public-private partnership to manage solid waste and when it failed, it became the main source of air pollution in the city. After a while in 2011, CPCB made an assessment in six cities of which Kanpur was among and it was found out that the industries are the main source of air pollution and the next was burning of solid waste in an open space, dust from roads and also domestic cooking in the city of Kanpur. (CPCB, 2011).

CHAPTER TW0

LITERATURE REVIEW

https://www.niehs.nih.gov/health/topics/agents/air-pollution/index.cfm

Air pollution is a mix of hazardous substances from both human-made and natural sources.

The major anthropogenic sources of air pollution.

- Vehicular emissions
- fuel oils and natural gas for domestic sources
- by-products of manufacturing and power generation,
- coal used in fuelling power plants
- fumes that are produced from chemical products

Natural sources of air pollution

- smoke from wildfires
- Ash and gases from volcanic eruptions
- Decomposition of organic matter in soils.

Air pollutants

Traffic-Related Air Pollution (TRAP), Vehicular emissions are said to be the major hazardous air pollutants. The air pollutants produced vehicles are anthropogenic. Examples include; some carbon compounds, ground-level ozone, oxides of nitrogen, oxides of sulphur, volatile organic compounds, polycyclic aromatic hydrocarbons, and fine particulate matter.

Ozone, is an atmospheric gas also known as smog while at ground level. an atmospheric gas, is often called smog when at ground level. Ozone is formed when oxides of Nitrogen react in the presence of sunlight.

Noxious gases, for example CO_2, CO, NOx, and SO_X, and all of them are compounds of vehicular emissions and from industrial production processes

Particulate matter (PM) contains chemicals of sulphates, nitrates, carbon, or mineral dusts. Vehicular and industrial emissions that are produced from burning of fossil fuel, smoking of cigarettes, and burning organic matter, for example burning of bushes.

There are two types of particulate matter that is fine particulate matter ($P.M_{2.5}$) and coarse particulate matter ($P.M_{10}$).

Volatile organic compounds (VOC) vaporize at or near room temperature—hence, the designation volatile. They are called organic because they contain carbon. VOCs are emitted from paints, cleaning products, pesticides, some furnishings, and from materials used for crafts such as glue. VOCs are mainly emitted from burning of natural gas and Gasoline.

Polycyclic aromatic hydrocarbons (PAH) are mainly a combination of Carbon and Hydrogen. These hazardous compounds are emitted industries during manufacturing of products like steel, iron, rubber, production of power. Polycyclic aromatic hydrocarbons are also components of particulate matter.

Control of Urban Pollution Series CUPS/82/2014-15, www.cpcb.nic.in

An air quality index is defined as an overall scheme that transforms the weighed values of individual air pollution related parameters (for example, pollutant concentrations) into a single number or set of numbers (Ott, 1978). The result is a set of rules (i.e., most set of equations) that translates parameter values into a simpler form by means of numerical manipulation (Figure below).

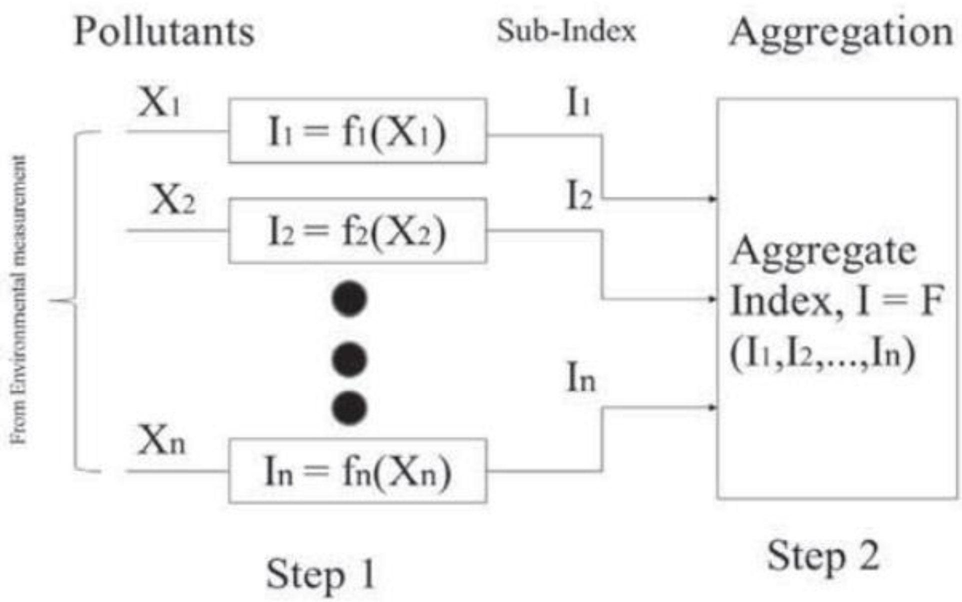


Figure 1: Drawing showing the formation of Air Quality Index

Index of pollutant doesn't have units. If given units, like µg/m3 or ppm (parts per million) together with permissible limits, then that's not ana index value. The last stage of indexing, is putting together the actual ranges of concentrations into descriptors of the quality of air.

Composition of an Index

Two major steps of formulating an Air Quality Index.

(i) Determining sub-indices of every pollutant

(ii) Determining the aggregate of the calculated sub-indices so as to find the final Air Quality Index.

Determining sub-indices I (I_1, I_2,., I_n) for n number of air pollutant variables X (X_1, X_2 ...., X_n) is done by use of sub-index function basing on the effects of concentrations of pollutants and air quality permissible limits.

Mathematical form of calculating sub-indices.

Eqn.1 $I_i = f(X_i)$, i=1, 2,...,n

Every sub-index is made up of the relationship between the concentrations of individual pollutant and its health effect on humans. With the help of function, sub-index I_i is related to the concentration of pollutant X_i according to the steps given below.

Eqn.2. $I= F (I_1, I_2 ,....,I_n)$

Figure1 shows the formation of an Aggregated Air Quality Index Central Pollution Control Board.

The aggregation function can the addition or just the highest operator or multiplying operations.

First step of determining Sub-indices.

Sub-index function represents the relationship between pollutant concentration X_i and corresponding sub-index I_i. It is an attempt to reflect environmental consequences as the concentration of specific pollutant changes. It may take a variety of forms such as linear, non-linear and segmented linear. Typically, the I-X relationship is represented as follows:

Eqn.3. $I = \alpha X + \beta$ Where, α =slope of the line, β = intercept at X=0.

The general equation for the sub-index (I_2) for a given pollutant concentration (Cp); as based on ‘linear segmented principle’ is calculated as:

Eqn.4. $I_i = [\{(I_{HI} – I_{LO})/ (B_{HI} -B_{LO})\} * (Cp -B_{LO})] + I_{LO}$

where,

B_{HI} = Breakpoint concentration greater or equal to given concentration.

B_{LO} = Breakpoint concentration smaller or equal to given concentration.

I_{HI} =AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

Ip = Pollutant concentration

2.2.2 Aggregation of Sub-indices (Step 2)

Once the sub-indices are formed, they are combined or aggregated in a simple additive form or weighted additive form:

Weighted Additive Form

Eqn.5. I = Aggregated Index = $\sum w_i I_i$ (For i= 1, …...,n)

where, $\sum w_i = 1$

I_i = sub-index for pollutant

I_n = number of pollutant variables

w_i = weightage of the pollutant

Root-Sum-Power Form (non-linear aggregation form)

Eqn.6. I = Aggregated Index = $[\sum I_i \; p] \; (1/p)$

where, p is the positive real number >1.

Root-Mean-Square Form

Eqn.7 I = Aggregated Index = $\{1/k \; (I1 \; 2 + I2 \; 2 + \ldots\ldots + Ik \; 2 \}0.5$

Minimum or Maximum Operator (Ott 1978)

Eqn.8. I = Min or Max $(I_1, I_2, I_3, \ldots, I_n)$

2. METHODS AND MATERIALS

Selection of cities

Cities were selected from states that lie in the Indo-Gangetic Plain. Preferably states that are neighboring the state of Delhi (Uttar Pradesh and Haryana), and further selected according to the availability of data from 2016 and also according to their population densities. They are seven cities considered, namely; Delhi, Varanasi, Agra, Kanpur, Lucknow, Rohtak and Faridabad.

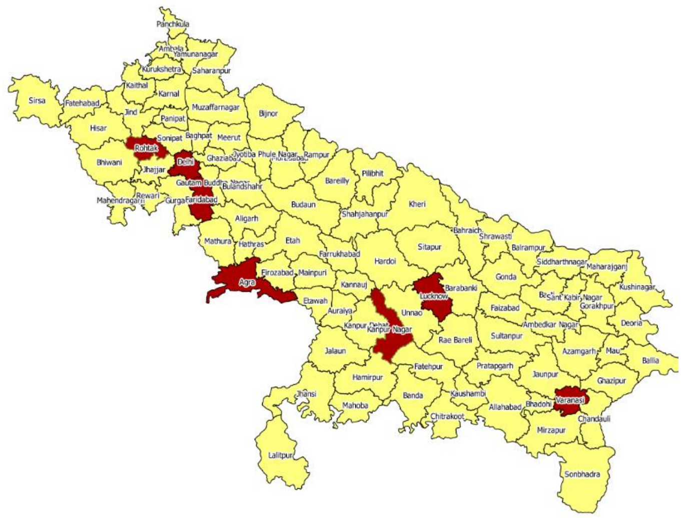


Figure 2; Map showing the location of states in India.   Figure 3;Map showing the location of 7 cities in the states

Data Sources

The concentration of different air quality pollutants from 1st January 2016 to 31st December 2020 and were taken from CPCB website (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing/data). The different pollutants are considered based on their 24-hr mean concentration (8h for O_3), these include NO_2, NO, $PM_{2.5}$, SO_2.

Data analysis

Using time series analysis, the daily concentration of pollutants in 2019 and 2020 was compared, and also before, after lockdown and during different relaxations of lockdown. Lockdown, means restricting vehicles, commercial flights except for cargo and charter, and prohibitions of commercial activities, except for essential services, resulting in a temporary shutdown of air pollution sources from these activities. The vertical line shows the start of 2020 covid-19 lockdown. The horizontal line in the graph shows the acceptable value of the pollutant. And the vertical line that is the line graph shows the beginning of lockdown 24th March 2020.

Air Quality Index

The AQI of sub-indices is calculated using the equation below and the final AQI is usually based on pollutants criteria where the deliberation of an individual pollutant is transformed into a sole index using appropriate aggregation method (Ott, 1978). Since all pollutants are not monitored simultaneously, to measure NAQI (National Air Quality Index) there should be data for three pollutants. Among them, either $PM_{2.5}$ or PM_{10} must be included. Also, data to be considered should be recorded for at least 16 hours. the air quality of a specific pollutant is defined by its sub-index.in 2015, CPCB outline the processes taken to calculate the National Air Quality Index. The steps are as follows;(Mahato et al., 2020)

Step 1;

$$\mathbf{I_n = [\{(I_{HI} - I_{LO}) / (B_{HI} - B_{LO})\} * (C_P - B_{LO})] + I_{LO}}$$

B_{HI} = Breakpoint concentration greater or equal to given concentration.

B_{LO} = Breakpoint concentration smaller or equal to given concentration.

I_{HI} = AQI value corresponding to B_{HI}

I_{HI} = AQI value corresponding to B_{HI}

I_{LO} = AQI value corresponding to B_{LO}

AQI = Maximum individual pollutant index, (I_P) (where; p= 1, 2…., denotes n pollutants)

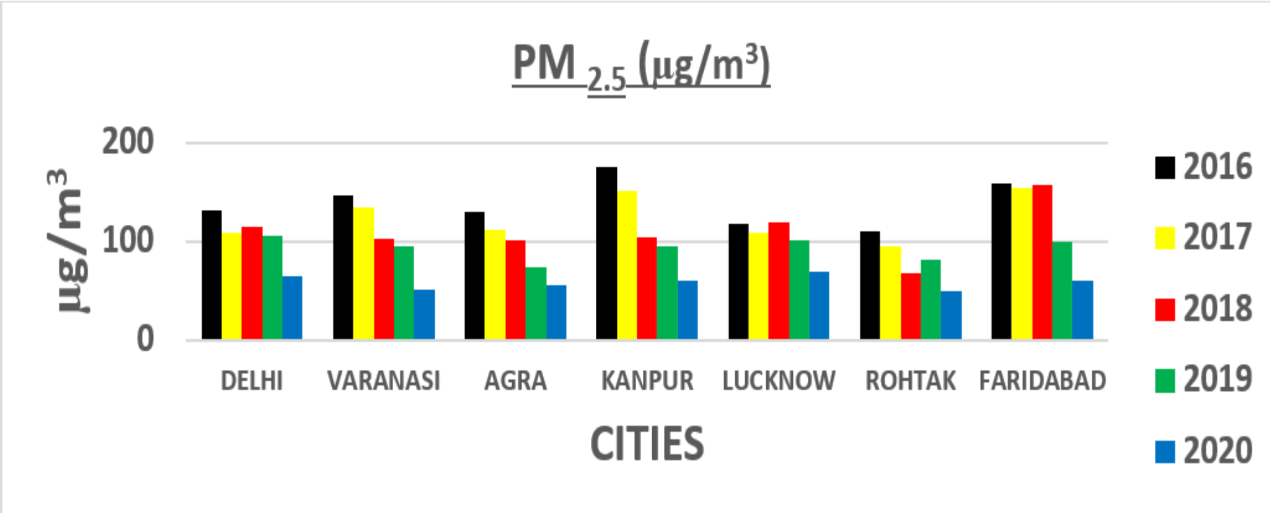
Step 2;

Minimum or Maximum Operator form (Ott, 1978):

I= aggregated Index= Minimum or Maximum, (I_1, I_2, I_3…..I_n)

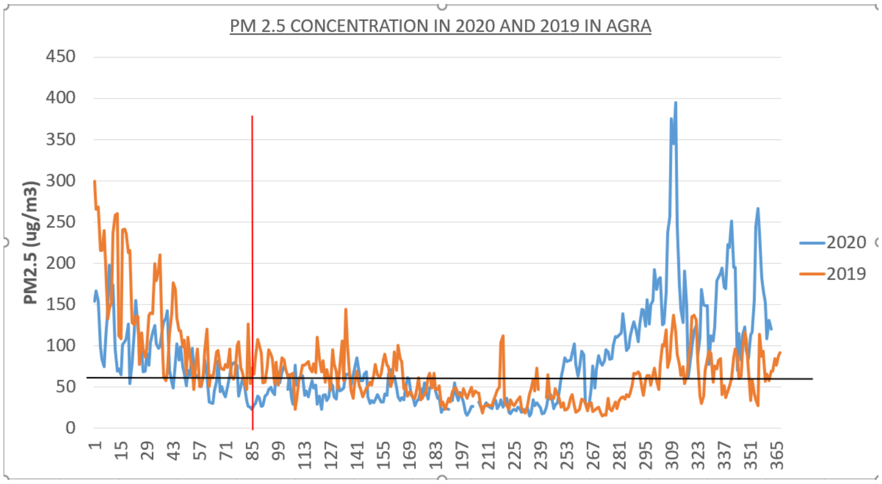
3. RESULTS AND DISCUSSION

PARTICULATE MATTER, PM 2.5



Since 2016, in all the seven cities, there is gradual decrease in the mean concentration of $PM_{2.5}$. this means that measures that were put in place to combat air pollution are effective

Comparison of mean concentration of $PM_{2.5}$ in 2019 and 2020 for all cities, it is observed that at the beginning of lockdown on the 82^{nd} day of the year, the concentration of $PM_{2.5}$ is lower than that of the same date of 2019. In September when lockdown was leased, it is observed that the concentration of $PM_{2.5}$ started increasing. Below are graphs that verify it. Therefore this could be the effect of meteorological factors and also the festive seasons that increases the anthropogenic sources of air pollution thus increasing the concentration of air pollutants in the atmosphere. It is observed from the line graphs below, the concentration of $P.M_{2.5}$ is low and well below the WHO permissible limit during the summer season of the region.



PM 2.5 CONCENTRATION IN 2020 AND 2019 IN AGRA
PM2.5 (ug/m3)
450
400
350
300
250
200
150
100
50
0
1
15
29
43
57
71
85
99
113
127
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239
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267
281
295
309
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337
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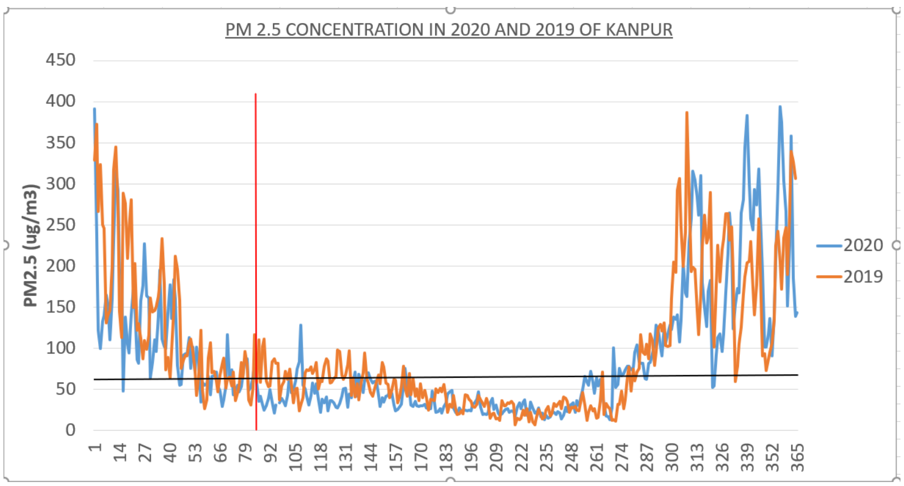
2020
2019



PM 2.5 CONCENTRATION IN 2020 AND 2019 OF KANPUR
PM2.5 (ug/m3)
450
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100
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40
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92
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118
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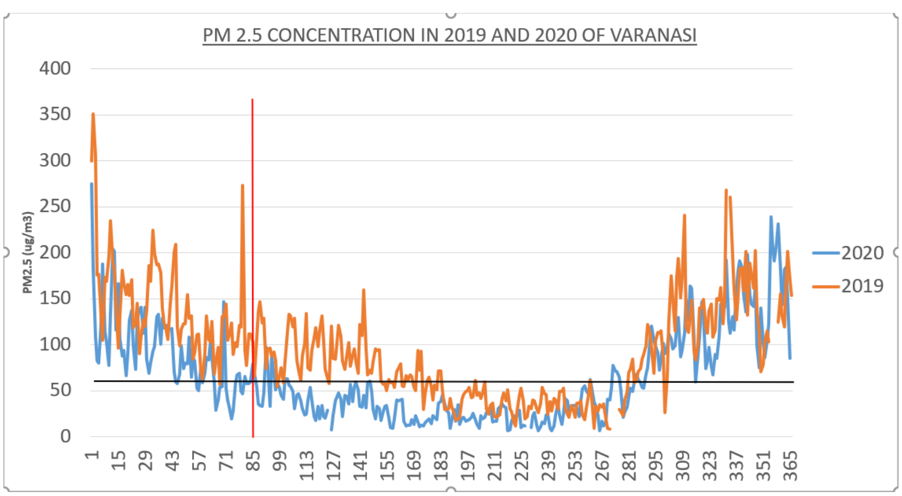
2020
2019



PM 2.5 CONCENTRATION IN 2019 AND 2020 OF VARANASI
PM2.5 (ug/m3)
400
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2020
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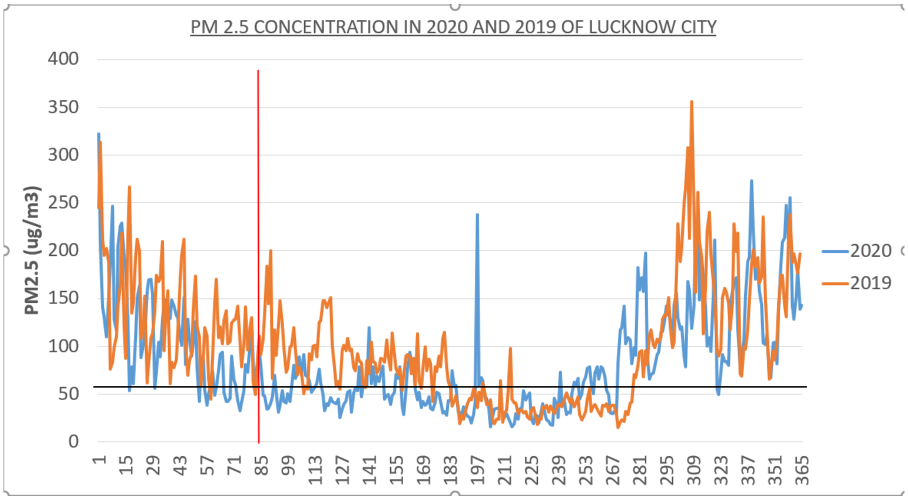
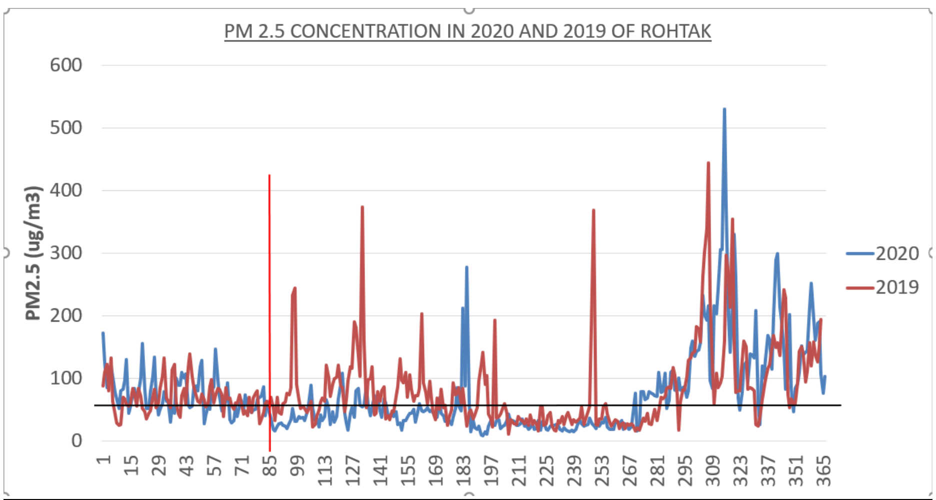
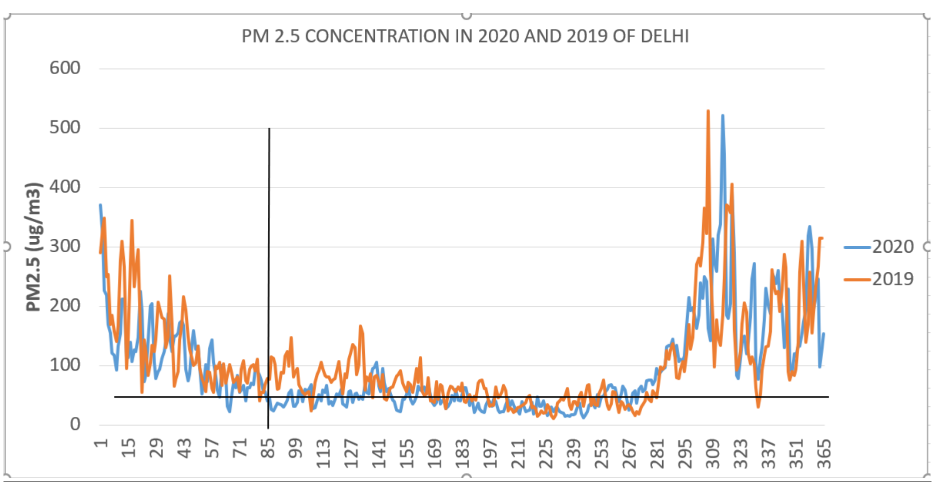
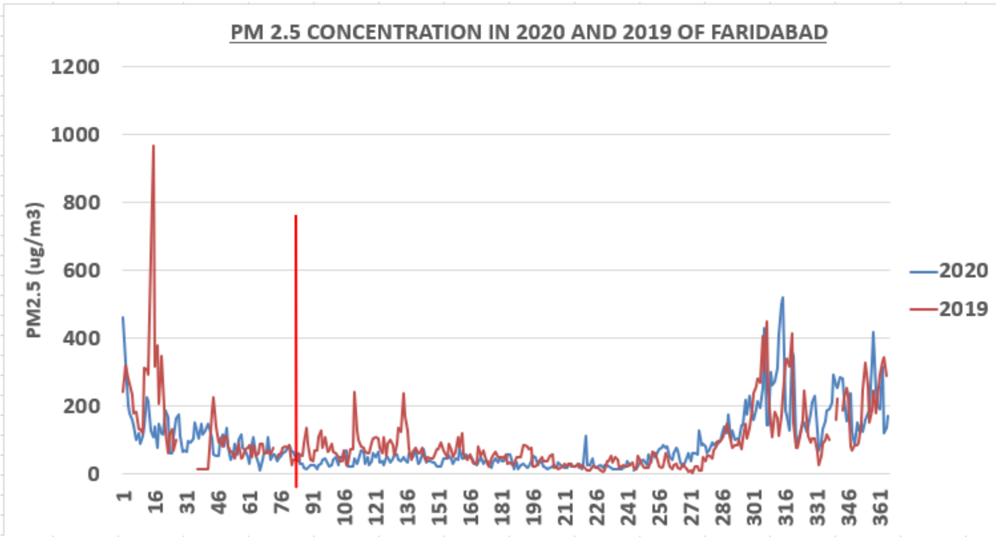
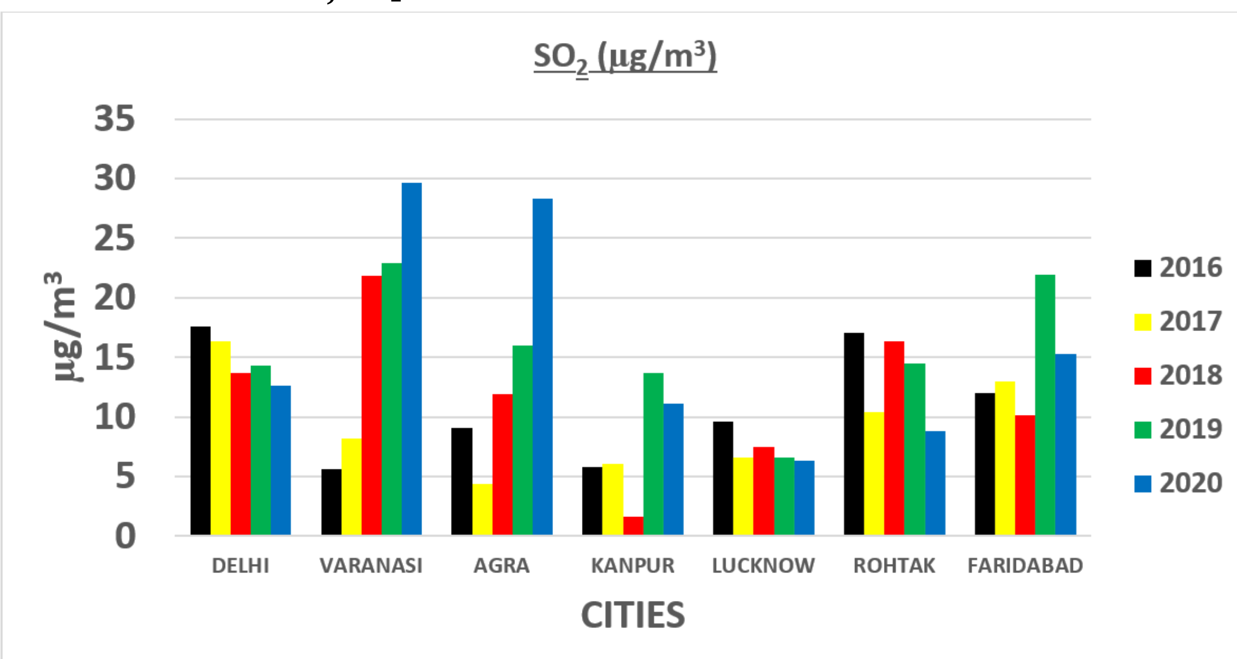

PM 2.5 CONCENTRATION IN 2020 AND 2019 OF LUCKNOW CITY
PM2.5 (ug/m3)
2020
2019


PM 2.5 CONCENTRATION IN 2020 AND 2019 OF ROHTAK
PM2.5 (ug/m3)
2020
2019


PM 2.5 CONCENTRATION IN 2020 AND 2019 OF DELHI
PM2.5 (ug/m3)
2020
2019

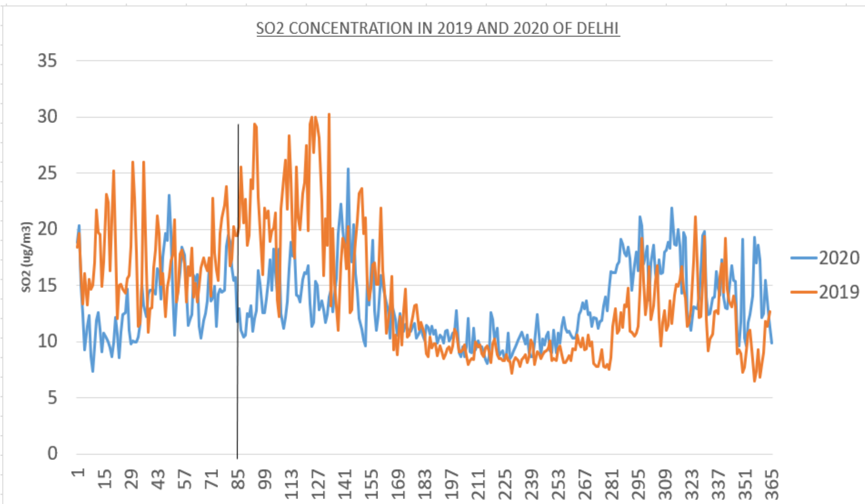


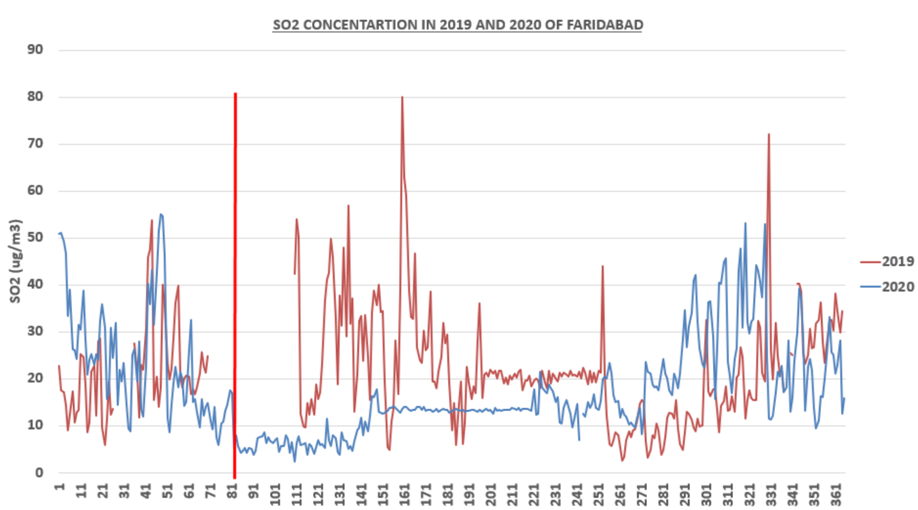
SULPHUR DIOXIDE, SO_2



Delhi shows a slight decrease in concentration of SO_2 over the years. In comparison of 2019 and 2020 concentration, there is a drop since lockdown started until when it ended. This could be due to closure of industrial activities due COVID -19.

Varanasi shows gradual increase in emission of SO_2. In comparison of 2019 and 2020 concentration there is an increase in emission from May 2020 lockdown relaxation of some activities started. Varanasi being the center for pilgrimage (Guttikunda et al., 2019), in May 2020 the rate of death due to corona virus increased, this could also be the reason for increase in emission. Concentration of SO_2 in Agra over the years has been increasing but in 2020, the concentration has increased greatly in air and most especially during lockdown. The unexpected increase in SO_2 in Agra is explained by the increase in coal consumption for heating coupled with inputs from the traditional fireworks during lockdown. In Kanpur, SO_2, has been increasing gradually, this is because of industrial emissions. The main sources of SO_2 in Kanpur are industries and domestic cooking, and since during lockdown industries were closed, but there is stiff increase in SO_2 concentration, it means that domestic cooking is major cause SO_2 emission in the air (CPCB, 2011). Lucknow shows yearly drop in SO_2 emission and during the lockdown there was a slight increase in emission compared to the same time in 2019.





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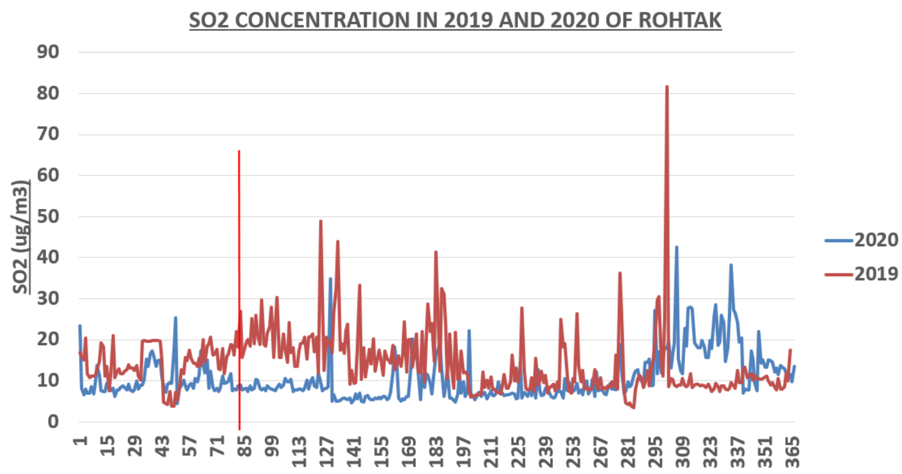
SO2 CONCENTRATION IN 2019 AND 2020 OF ROHTAK
SO2 (ug/m3)
90
80
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2020
2019
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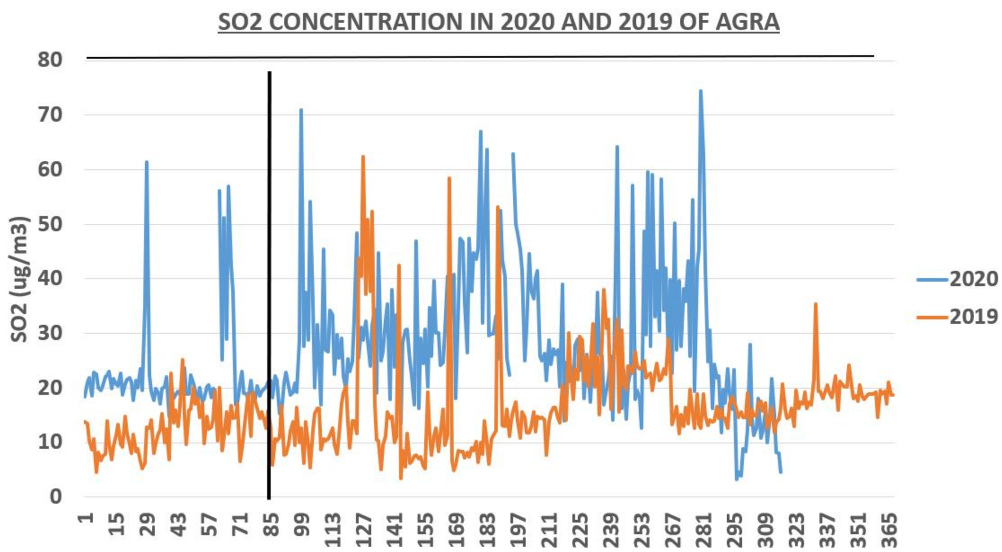
SO2 CONCENTRATION IN 2020 AND 2019 OF AGRA
SO2 (ug/m3)
80
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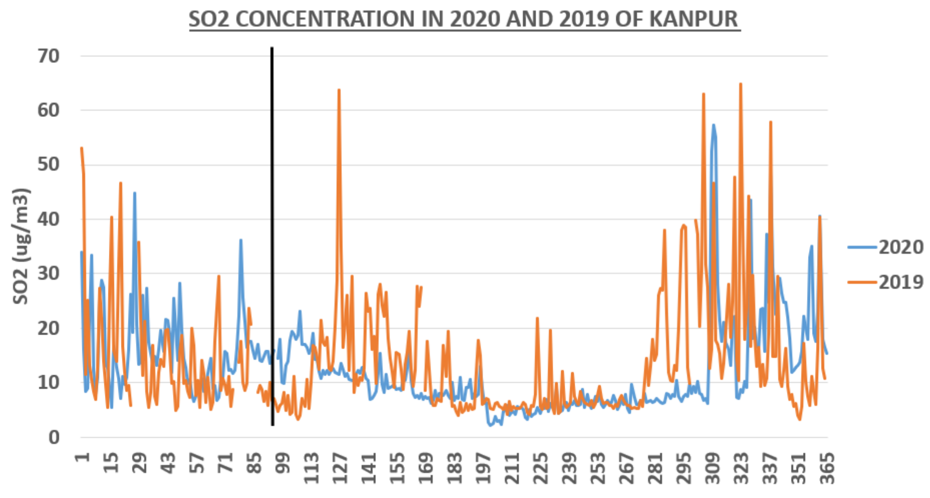
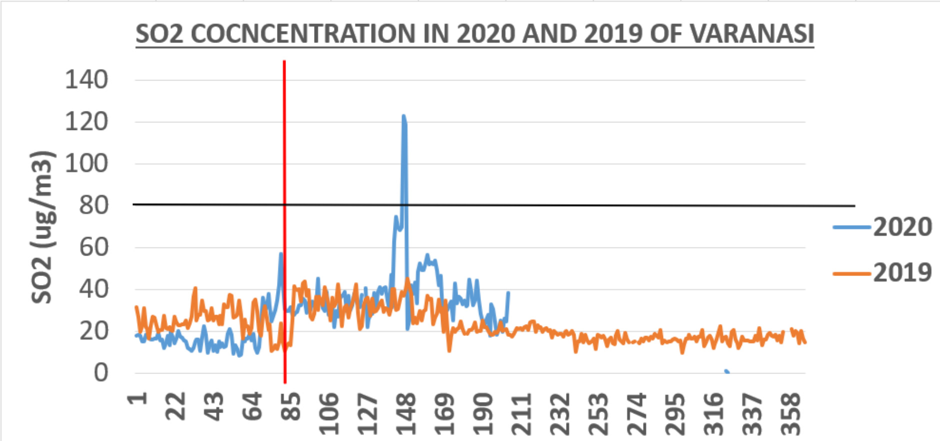
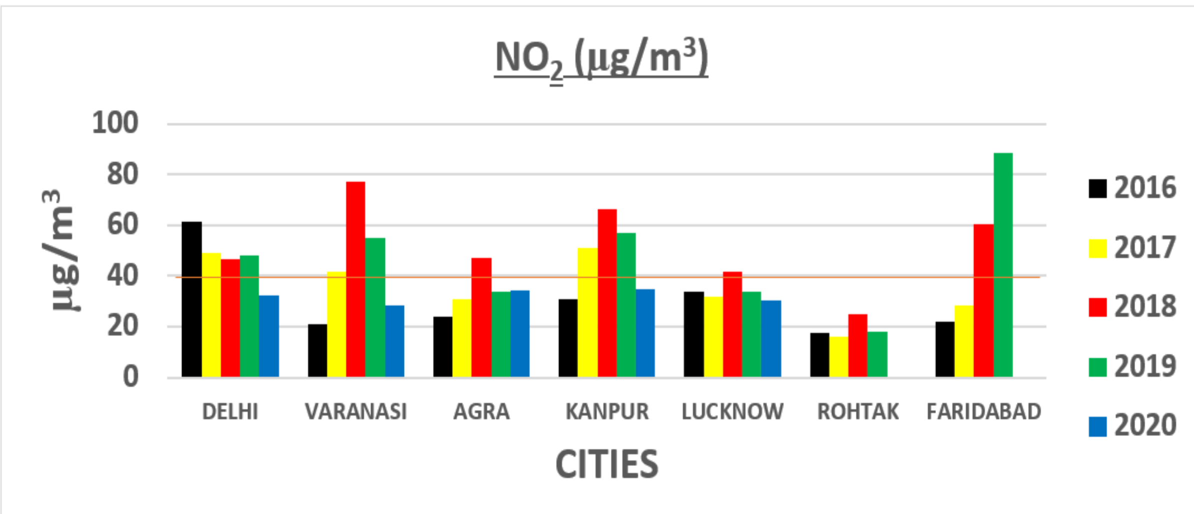




NITROGEN DIOXIDE (NO_2)



Delhi has gradual reduction in NO_2 emissions over the past five years, though it the annual average emission was still above the annual permissible standards of India. This could be because some vehicles use CNG as fuel. But in 2020, there is great average reduction of emission and this is because of lockdown due to COVID-19 and it is even within the required standards according to India’s standards. Since NO_2 comes from combustion of fossil fuel from vehicles and industries, they were stopped from moving.

Varanasi shows gradual increase in emission of NO2 up to 2018 and from 2018, there is decrease in emission up to 2020. In 2019, the average annual emission was 54.96μg/m^3 and it reduced to 28.55μg/m^3 which is below the National Air Quality standards.

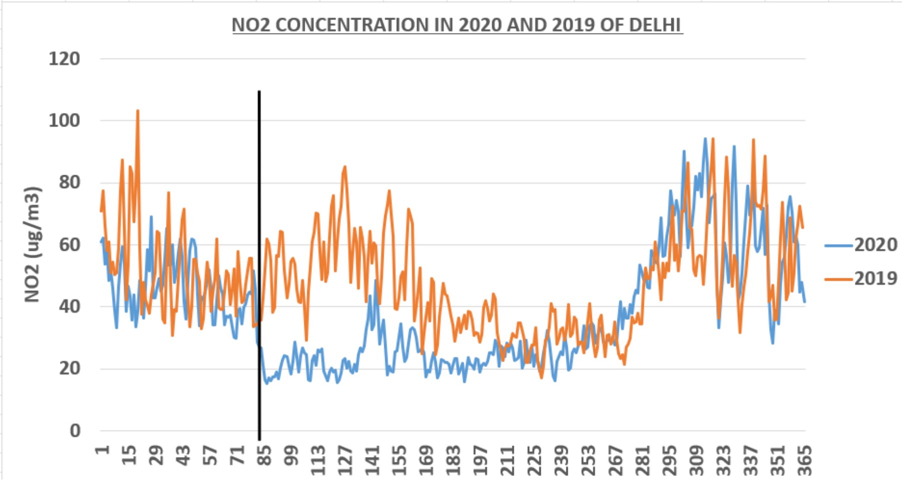
Agra shows to have had its emissions to be below the National Air Quality standards apart from 2018 when the average annual emission was 47 μg/m^3 which is 7 μg/m^3 above the required annual concentration.

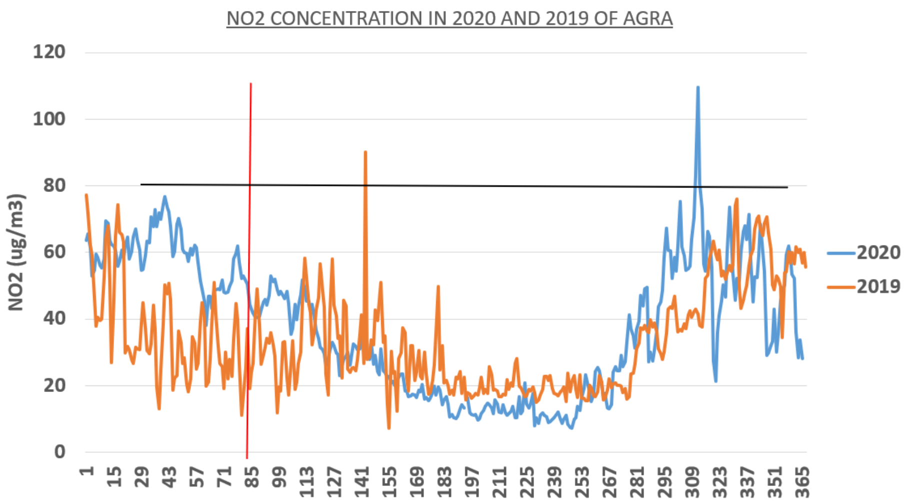
Kanpur increase in average annual emission from 2016, 2017 and 2018 (30.75μg/m^3, 51.11μg/m^3, 66.44 μg/m^3 respectively) and there is reduction in 2019 and 2020 (57.13μg/m^3, and 34.86μg/m^3 respectively)

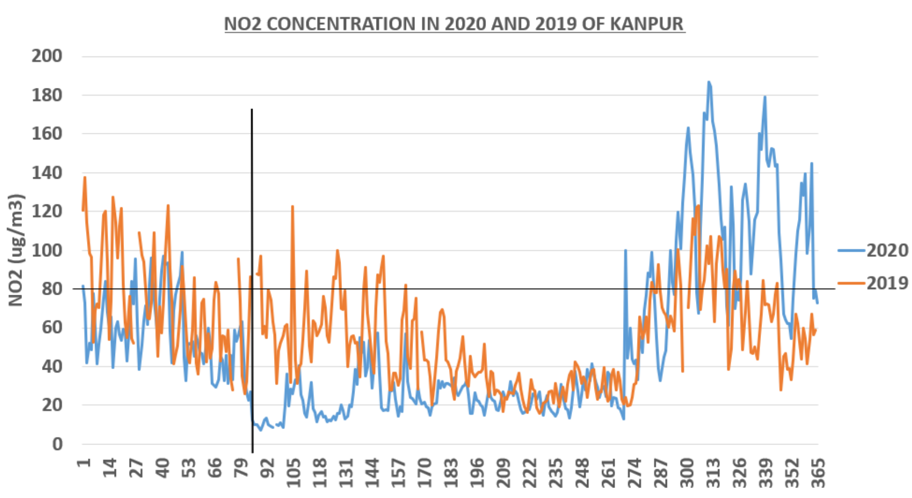
Lucknow shows relative no change in emission and its emission lies with the required National Air Quality Standards.

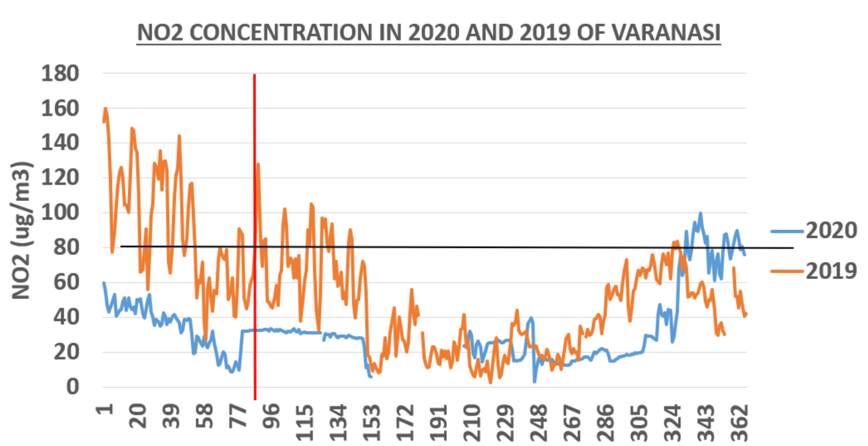
Rohtak shows tits emission to be below the required NAQS.

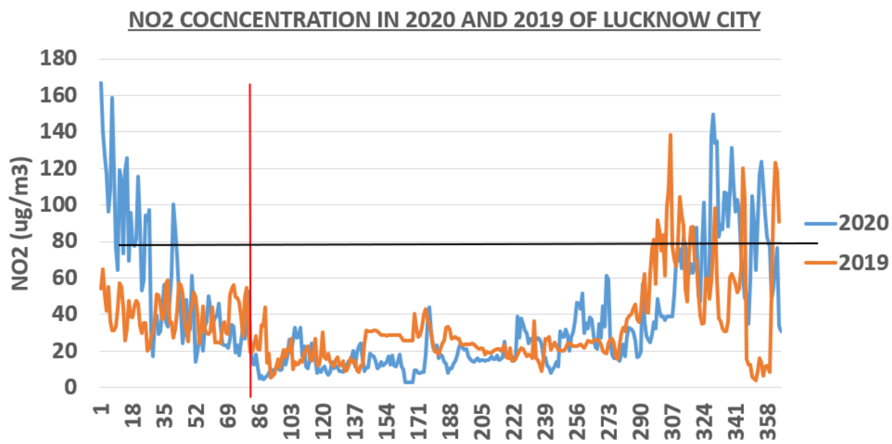
Faridabad shows increase in emission since 2016, and in 2018 and 2019, the annual average emission went above the required National Air Quality Standards. 2020 is not analyzed due to unavailability of data.


NO2 CONCENTRATION IN 2020 AND 2019 OF DELHI
NO2 (ug/m3)
2020
2019

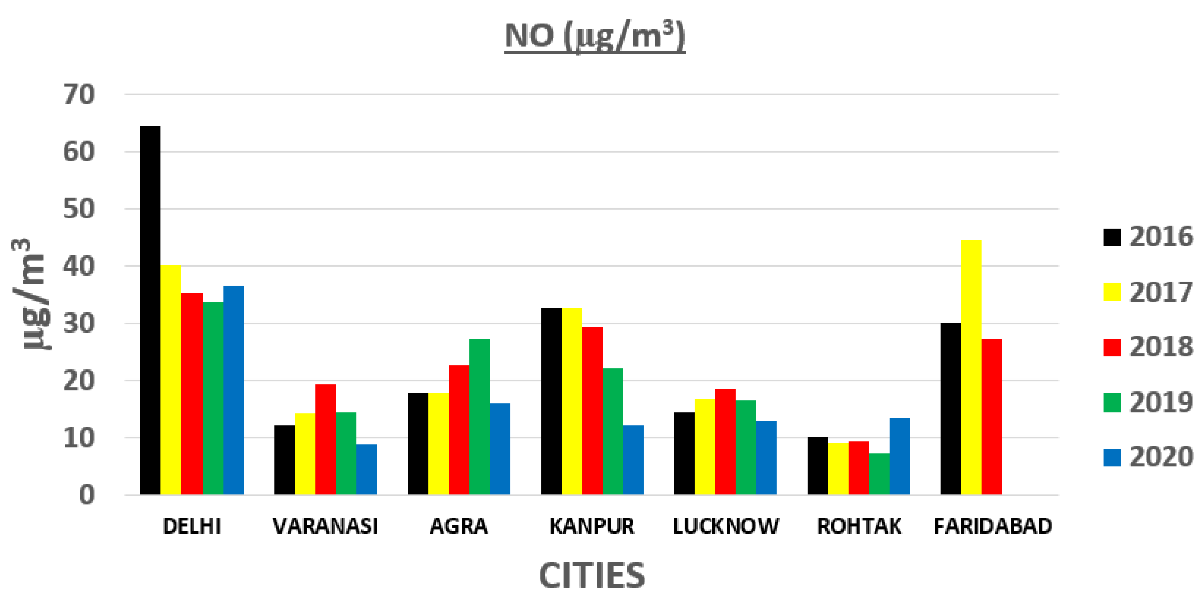

NO2 CONCENTRATION IN 2020 AND 2019 OF AGRA
NO2 (ug/m3)
2020
2019


NO2 CONCENTRATION IN 2020 AND 2019 OF KANPUR
NO2 (ug/m3)
2020
2019





NITROGEN OXIDE, (NO)



Delhi shows decrease in mean concentration of Nitrogen oxide in the atmosphere over the years, from 2016 to 2019, and 2020 it shows slight increase in mean annual concentration in the atmosphere. This could be due to COVID-19 lockdown where all vehicles were stopped from moving.

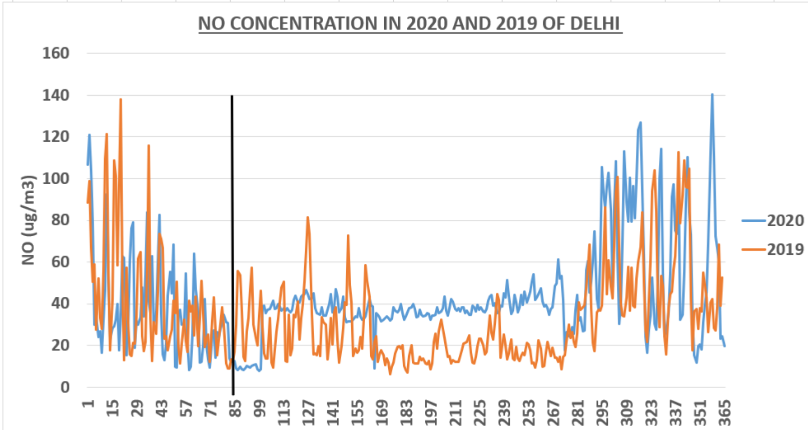
Varanasi show increase in annual mean concentration from 2016 to 2018 and reduced in 2019 and 2020. Agra shows increase in concentration from 2016 to 2019 and great decrease of 11.11µg/m^3 in concentration in 2020. Kanpur show systematic decreases in annual mean concentration over the years. Lucknow shows increase in annual mean concentration from 2016 to 2018 and decreases from 2019 to 2020. Rohtak shows slight decrease in concentration from 2016 to 2019 and greatly increases in 2020. Faridabad shows fluctuating mean annual concentration from 2016 to 2018. And there is no available data for 2019 and 2020.

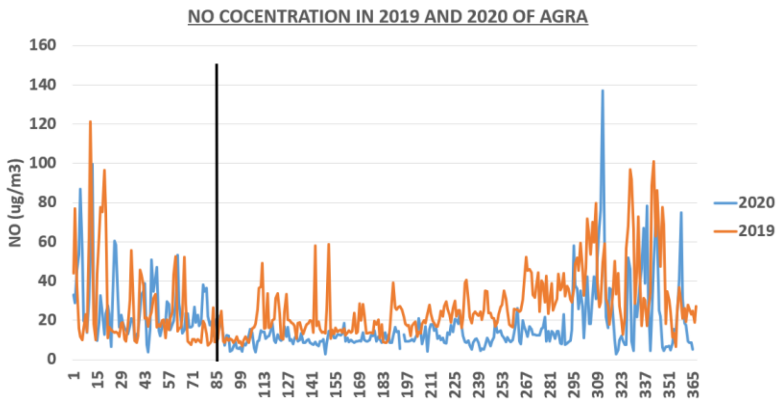
There is direct source of Nitrogen oxide. It is formed by the reaction of gases in the atmosphere with the help of sunlight and high temperatures.

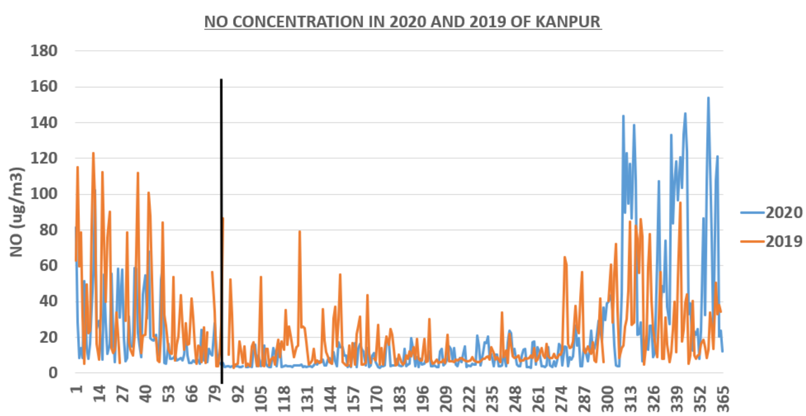
Lucknow, Varanasi, Kanpur and Agra show less concentration of nitrogen oxide in the 2020 than 2019. But it shows the same trend, therefore there is no effect caused by lockdown since they show no difference on after and before lockdown, for both years.

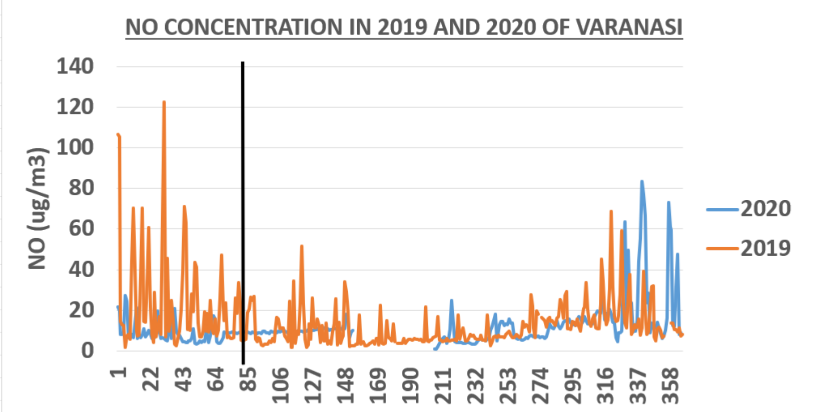
CPCB has no recorded data of Nitrogen oxide for Faridabad and Rohtak.

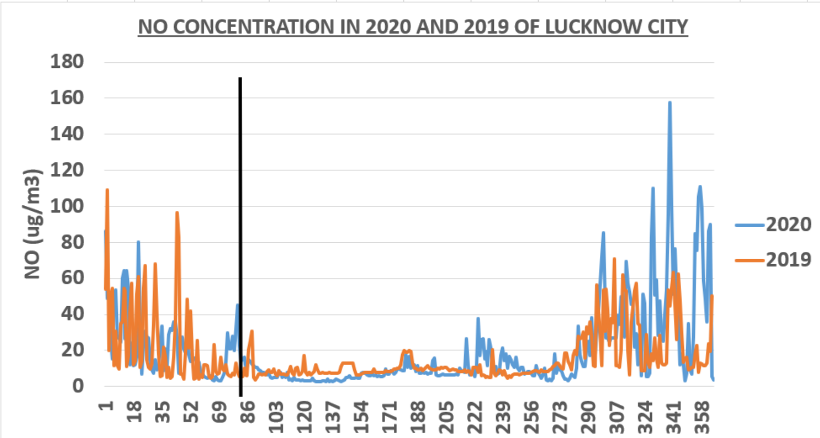
Delhi shows higher concentration of Nitrogen oxide for 2020 than for 2019 and there no significant effect on concentration of nitrogen oxide in the atmosphere caused by lockdown due to Covid-19 pandemic.


NO CONCENTRATION IN 2020 AND 2019 OF DELHI
NO (ug/m3)
2020
2019

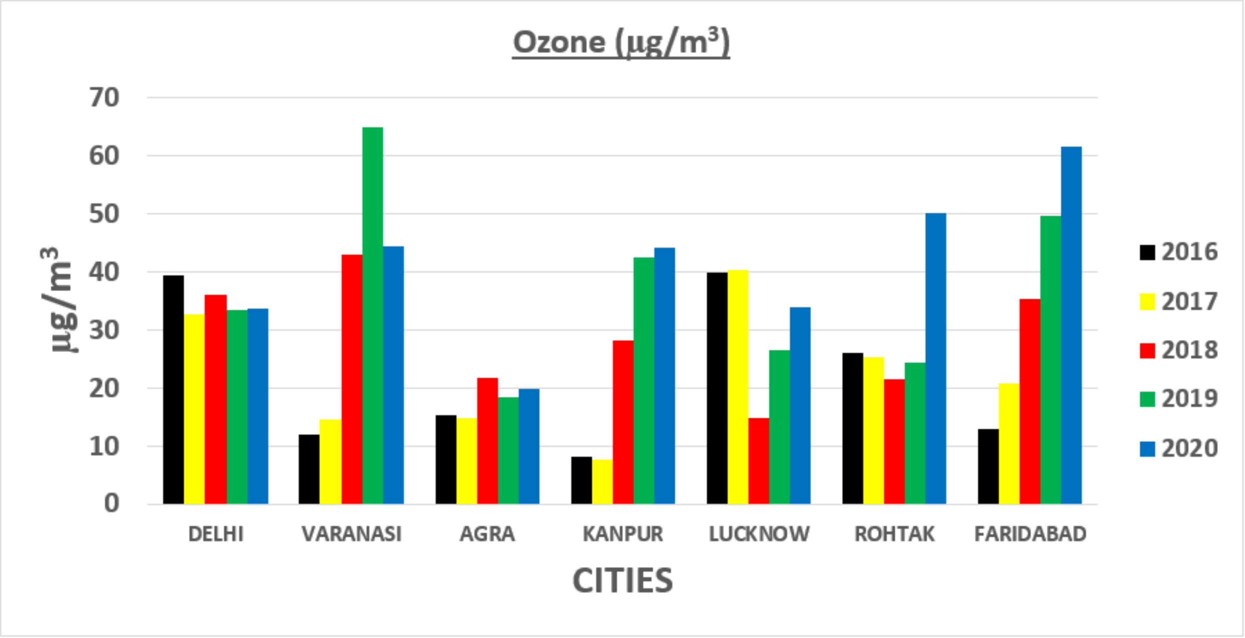

NO COCENTRATION IN 2019 AND 2020 OF AGRA
NO (ug/m3)
2020
2019


NO CONCENTRATION IN 2020 AND 2019 OF KANPUR
NO (ug/m3)
2020
2019


NO CONCENTRATION IN 2019 AND 2020 OF VARANASI
NO (ug/m3)
140
120
100
80
60
40
20
0
1
22
43
64
85
106
127
148
169
190
211
232
253
274
295
316
337
358
2020
2019


NO CONCENTRATION IN 2020 AND 2019 OF LUCKNOW CITY
NO (ug/m3)
180
160
140
120
100
80
60
40
20
0
1
18
35
52
69
86
103
120
137
154
171
188
205
222
239
256
273
290
307
324
341
358
2020
2019

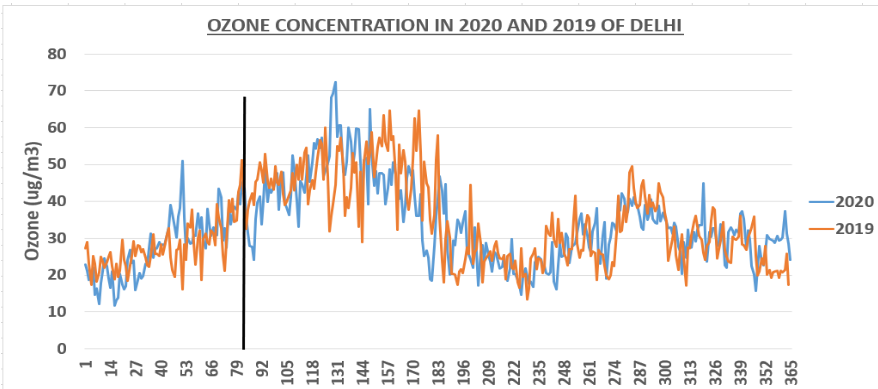
OZONE O_3

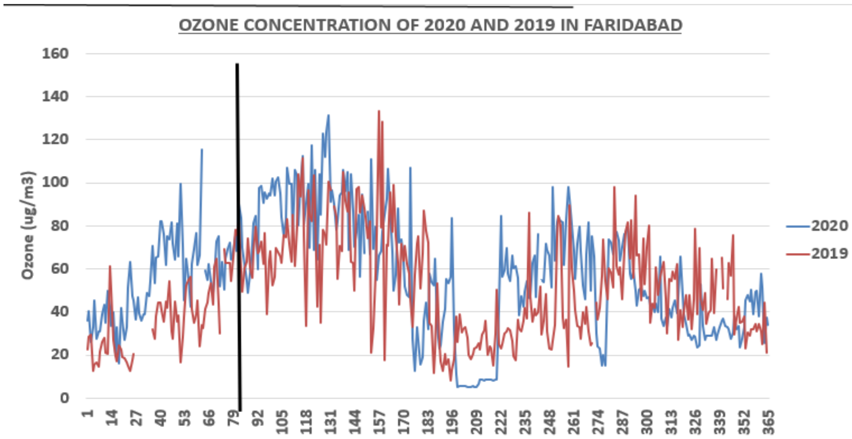


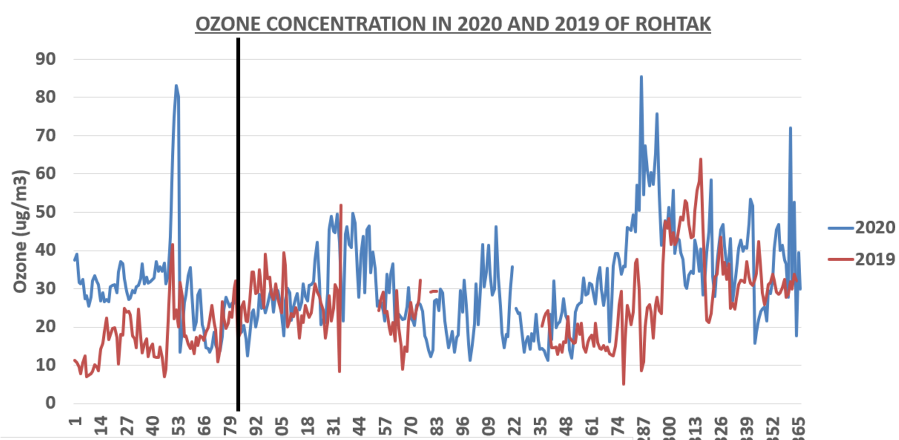
From April to August is believed to be a season where O_3 concentration is high in the subcontinent of India because of increasing insolation (Gorai et al., 2017). Industrial areas and areas where transport is dominated is where there is an increment in concentration of Ozone and those areas there is limited Nitrogen oxide which causes the decrease of O_3 consumption. This is easily observed through the equation that formed by a titration process ($NO + O_3 = NO_2 + O_3$) and this process leads to production of Ozone thus increasing its concentration in the atmosphere(Mahato et al., 2020). 0ver the years, from 2016 to 2020, there is gradual increase of O_3 concentration in the atmosphere in all the cities apart from Varanasi where 2019 concentration is the highest ever recorded in all the years. Also, Lucknow in 2018, it recorded its lowest O_3 concentration (14.75µg/m^3). Rohtak recorded the highest increase of Ozone concentration in the year 2020 (25.62µg/m^3). Many researchers say that due to lockdown in 2020, it has led to the increase in concentration during the lockdown. But my research proves this wrong, by comparing ozone concentration in the year 2019 and 2020, the graph shows similar trend concentration of ozone for both years even during the lockdown period in 2020.

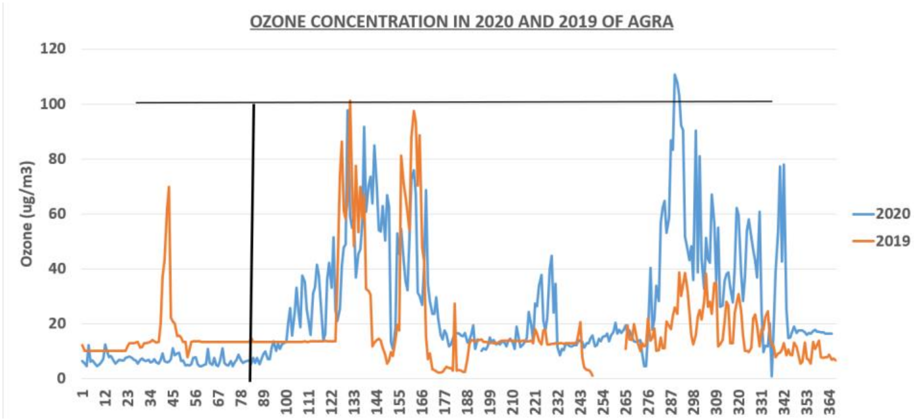
To determine the decrease of concentration of the pollutant, there is a need to first determine the effect of fluctuations that happen shortly and the trends that happen seasonally during the time when the analysis is being done. According to the analysis, meteorological factors, seasonal, anthropogenic and also cultural factors also caused an effect on the trends. (Chen et al., 2015;

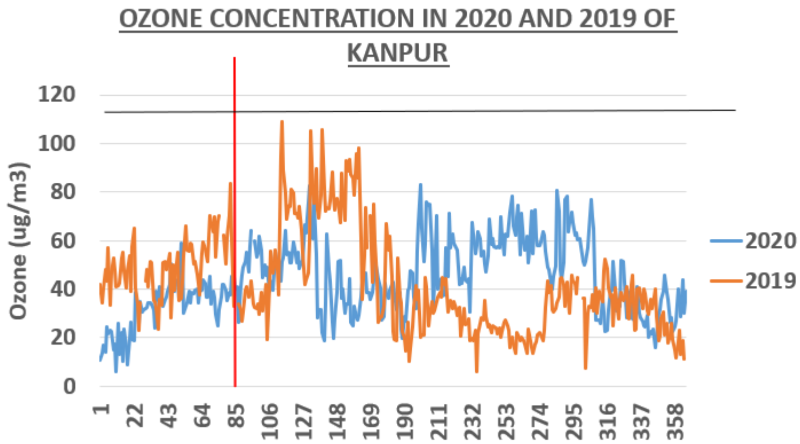
Cichowicz et al., 2017; Mohtar et al., 2018). Zangari et al. (2020). Hence, we tested the daily time series of the ambient air quality data of the stations from January to September of 2019 and 2020 for the presence of trends.(Thomas et al., 2020). The trend of ozone for 2020 and 2019 is the same however, there is some slight increase in concentration in the year 2020 immediately after the lockdown. It is seen in all city under this study that the ozone concentration increases during spring season of the year because the sunlight is clear and a lot during the season.

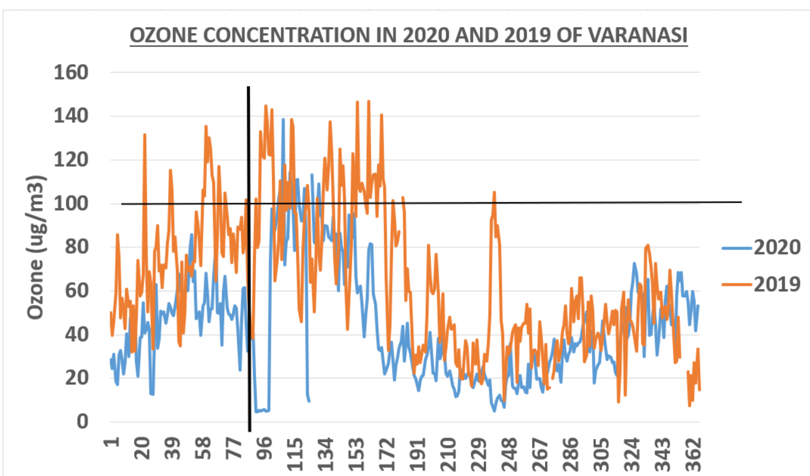


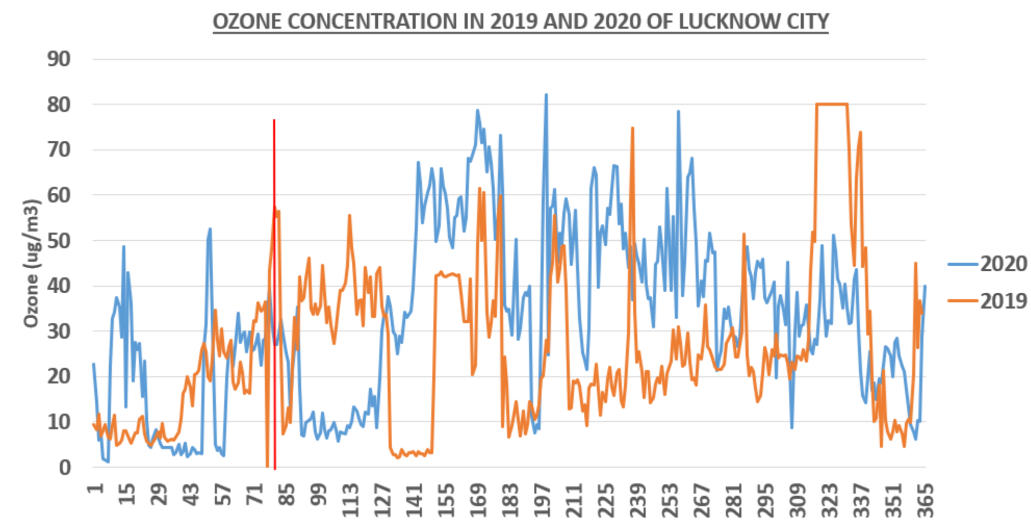





OZONE CONCENTRATION IN 2020 AND 2019 OF AGRA
Ozone (ug/m3)
2020
2019


OZONE CONCENTRATION IN 2020 AND 2019 OF KANPUR
Ozone (ug/m3)
2020
2019


OZONE CONCENTRATION IN 2020 AND 2019 OF VARANASI
Ozone (ug/m3)
2020
2019


OZONE CONCENTRATION IN 2019 AND 2020 OF LUCKNOW CITY
Ozone (ug/m3)
90
80
70
60
50
40
30
20
10
0
1
15
29
43
57
71
85
99
113
127
141
155
169
183
197
211
225
239
253
267
281
295
309
323
337
351
365
2020
2019

Spatial analysis using AQI

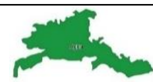
Periods considered in spatial analysis are selected in accordance to lockdown phases. Country wide lockdown started on 24th March 2020, on 1st June 2020, the prime minister announced the relaxation of lockdown and it only remains in containment zone. (Wikipedia) From June they lockdown changed to unlock 1and in September most of the activities were unlocked, thus the four periods of the spatial analysis.

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
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 polluted (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	10-17	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+

Figure 8: Break points for air quality index (AQI) scale (0- 500) in µg/m^3 unless mentioned.

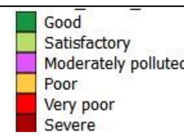
Table 1: spatial analysis of the subindex of mean concentration of NO_2

CITY	TIME PERIOD	2019	2020	LEGEND
ROHTAK	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
DELHI	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			

	31st Sep – 31st Dec			
VARANASI	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
AGRA	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
LUCKNOW	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
KANPUR	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			

In Rohtak the concentration NO_2 was not affected by lockdown according to the sub-index of the pollutant. It is only in the last quarter of 2020 where the Air Quality sub-index increased from good to satisfactory as compared to 2019 and the previous quarter. This could be due different activities opening in that quarter. Delhi shows change in concentration of NO_2 after lockdown from satisfactory to good in the year 2020 and the last quarter of the year when most of the activities were unlocked which is also similar to last quarter of 2019. This could be due to dispersion effect caused by weather changes due to winter in the December that affects the dispersion of pollutants. In Varanasi the concentration of NO_2 using sub- index analysis shows great improvement in 2020, but no effect is caused due to covid-19 lockdown which started on 24th march 2020. In Agra the concentration of NO_2 using sub- index analysis improved in 2020 after covid-19 lockdown from satisfactory to good and in the last quarter of the year, it changed from good to satisfactory. However also in 2019 during the last quarter of the year, it was also satisfactory. This could be due to dispersion that is affected by weather in the last quarter of the year. Comparing 2019 and 2020 before the lockdown, Lucknow has good air quality in 2019 and satisfactory in 2020. Which means that the concentration of NO_2 in 2020 had increased. After the lockdown, the concentration of NO_2 to being and the next quarter also was good which is similar to 2019, the last quarter, it increased to being satisfactory, this could be due to dispersion that is caused by change in weather and the unlock of some activities. In Kanpur Nagar, the sub-index of NO_2 in was satisfactory before lockdown of 2020 and also the same period in 2019. After the lockdown in 2020 it improved to be being good but in 2019 the same period it remained satisfactory. From 31st June to 31st September of both years the subindex of NO_2 shows good. From 31st September to 31st December of 2020, it increased to moderately polluted, and in 2019 the same period shows satisfactory. This could be due to unlock of some activities in 2020 and the development.

Table 2: Spatial analysis of sub-index of mean concentration of $PM_{2.5}$ of cities

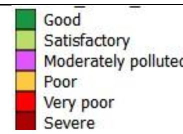
CITY	TIME PERIOD	2019	2020	LEGEND
ROHTAK	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
DELHI	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
VARANASI	1st Jan – 24th Mar			

	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
AGRA	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
FARIDABAD	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
LUCKNOW	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
KANPUR	1st Jan – 24th Mar			
	24th Mar – 31st June			

	31st Jun – 31st Sep			
	31st Sep – 31st Dec			

In Rohtak, before the 2020 COVID-19 lockdown it was moderately polluted with $PM_{2.5}$ and also the same period of 2019. After the lockdown, there was improvement from moderately polluted to good, but the same period of 2019, it was still moderately polluted. From 31st June – 31st September of both years, it was satisfactorily polluted. From 31st September to 31st December, it was very poorly polluted for both years even when some activities like schools and international flights have not yet resumed. Which means that those activities have less effect on pollution. Delhi was poorly polluted with $PM_{2.5}$ before 2020 COVID-19 lockdown and very poorly polluted in 2019 during the same period. After the lockdown in 2020 the concentration of $PM_{2.5}$ was satisfactory and moderately polluted in 2019 showing that there is an effect of lockdown but also it could be as a result of meteorological factors as we can that that also 2019 during the same period improved. From 31st June to 31st September for both years the concentration was satisfactory showing that lockdown has less effect on the pollutant concentration. From 31st September to 31st December of both years, Delhi was very poorly polluted with $PM_{2.5}$. this shows that whether there is lockdown or not, Delhi is very poorly polluted. Other measures should be put in place. In Varanasi, before 2020 COVID-19 lockdown, it was poorly polluted with $P.M_{2.5}$ and in 2019 during the same period it was very poorly polluted. This could be due to air pollution control measures are fairly working. After lockdown in 2020, the concentration was satisfactory and in 2019, it was moderately polluted. This shows that lockdown was effective and in 2019, it could be to meteorological factors. From 31st June to 31st sept was satisfactory for both years; this could be due meteorological factors with the effect of lockdown for the year 2020. From 31st sept to 31st December 2020, Varanasi was poorly polluted and for 2019, it was very poorly polluted. This shows that the effect of lockdown and air pollution measures put in place by the government. Agra was moderately polluted with $PM_{2.5}$ from before COVID-19 lockdown in 2020 and very poorly polluted during the same period in 2019. The difference in concentration of the years could be because of different measures put in place by the government to combat air pollution. After lockdown the concentration is satisfactory for 2020 and moderately polluted for 2019 during the same period. From 31st June to 31st September of both years, it shows the concentration of the pollutant is satisfactory according to sub-index analysis. From 31st September to 31st December of 2020, Agra was very poorly polluted and during the same period of 2019, it was moderately polluted. Faridabad was poorly polluted before the 2020 COVID-19 lockdown and very poorly polluted during same period in 2019. After the lockdown from 24th march to 31st June the concentration of the pollutant was satisfactory as classified by air quality index. During the same period in 2019, the pollutant concentration reduced to moderately polluted. From 31st June to 31st September of both years, the pollutant concentration was satisfactory. This shows less effect lockdown, however most of the activities was already unlocked. Therefore, this could be due to meteorological factors. From 31st September to 31st December of both years, pollution is very poor caused by $PM_{2.5}$. This shows that during that period, the pollution caused by $PM_{2.5}$ is very poorly polluted. Lucknow was poorly polluted before the 2020 COVID-19 lockdown and very poorly polluted during same period in 2019. After the lockdown from 24th march to 31st June the concentration of the pollutant was satisfactory as classified by air quality index. During the same period in 2019, the pollutant concentration reduced to poorly polluted. From 31^{st} June to 31^{st} September of both years, the pollutant concentration was satisfactory. This shows less effect of lockdown, however most of the activities was already unlocked. Therefore, this could be due to meteorological factors. From 31^{st} September to 31^{st} December of both years, pollution is very poor caused by $PM_{2.5}$. This shows that during that period, the pollution caused by $PM_{2.5}$ is very poorly polluted. Kanpur Nagar was poorly polluted before the 2020 COVID-19 lockdown and very poorly polluted during same period in 2019. After the lockdown from 24^{th} march to 31^{st} June the concentration of the pollutant was satisfactory as classified by air quality index. During the same period in 2019, the pollutant concentration reduced to moderately polluted. From 31^{st} June to 31^{st} September of 2020, the pollutant concentration was satisfactory and good for 2019, the pollutant concentration was satisfactory. This shows less effect lockdown, however most of the activities was already unlocked. Therefore, this could be due to meteorological factors. From 31^{st} September to 31^{st} December of both years, pollution is very poor caused by $PM_{2.5}$. This shows that during that period, the pollution caused by $PM_{2.5}$ is very poorly polluted.

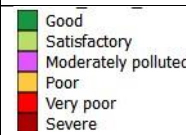
Table 3: Spatial analysis of the sub-index of mean concentration of ozone of cities

CITY	TIME PERIOD	2019	2020	LEGEND
ROHTAK	1^{st} Jan – 24^{th} Mar			
	24^{th} Mar – 31^{st} June			
	31^{st} Jun – 31^{st} Sep			
	31^{st} Sep – 31^{st} Dec			
DELHI	1^{st} Jan – 24^{th} Mar			
	24^{th} Mar – 31^{st} June			
	31^{st} Jun – 31^{st} Sep			
	31^{st} Sep – 31^{st} Dec			
VARANASI	1^{st} Jan – 24^{th} Mar			
	24^{th} Mar – 31^{st} June			
	31^{st} Jun – 31^{st} Sep			
	31^{st} Sep – 31^{st} Dec			
AGRA	1^{st} Jan – 24^{th} Mar			
	24^{th} Mar – 31^{st} June			

	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
FARIDABAD	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
LUCKNOW	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
KANPUR	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			

In Rohtak, ozone concentration in the atmosphere is good through the two years and before the lockdown and after lockdown. In Delhi, the pollution of ozone in the atmosphere was good through the two years and before the lockdown and after lockdown. In Varanasi, before 2020 COVID- 19 lockdown, the pollution of Ozone was poor and during the same period in 2019, it was good. After the lockdown, the pollution of the pollutant was satisfactory for both years. From 31st June – 31st September of 2020, the pollution of the pollutant was satisfactory and good during the same period in the year 2019. From 31st September to 31st December of 2020, the pollution of the pollutant was poor and was good for the same period in the year 2019. In Agra, the pollution of ozone in the atmosphere was good through the two years and before the lockdown and after lockdown. In Faridabad, before the 2020 COVID-19 lockdown, the pollution of ozone was satisfactory and good during the same period of 2019. After the lockdown the pollution of ozone was satisfactory for both years and good for the rest of year for both years. In Lucknow, the pollution of ozone in the atmosphere was good through the two years and before the lockdown and after lockdown. In Kanpur Nagar the pollution of ozone before the 2020 COVID-19 lockdown, was good and satisfactory in 2019 during the same period. It remained good even after lockdown and also remained satisfactory in 2019 during the same period. From 31st June to 31st September in 2020, it decreased to satisfactory and improved to good in 2019 during the same period. From 31st September to 31st December of both years was good.

Table 4:Spatial analysis of the sub-index of mean concentration of SO_2

CITY	TIME PERIOD	2019	2020	LEGEND
ROHTAK	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
DELHI	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
VARANASI	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
AGRA	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			

	31st Sep – 31st Dec			
FARIDABAD	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
LUCKNOW	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			
KANPUR	1st Jan – 24th Mar			
	24th Mar – 31st June			
	31st Jun – 31st Sep			
	31st Sep – 31st Dec			

In all the cities, (Rohtak, Delhi, Varanasi, Agra, Faridabad Lucknow and Kanpur) the air quality index shows that the pollution of SO_2 in the atmosphere was good throughout the two years and before the lockdown and after lockdown.

4. CONCLUSION

During lockdown caused by COVID-19 pandemic, it is observed there has been an improvement in air quality in the Indo-Gangetic Plain cities. The study analyses concentration of four pollutants during four quarters of wo years, that is 2019 and 2020. However, by comparing the four pollutants of during different seasons of 2019 and 2020, the study shows that, not all the four pollutants got an effect because of COVID-19 lockdown. It might be because of the effect of dispersion caused by meteorological factors of pre-monsoon season, monsoon, and summer, during winter the air is greatly polluted and mostly with $PM_{2.5}$. And also due to 2020 COVID-19 lockdown, air quality improved in the year 2020, but most especially immediately after the lockdown. Its only in Varanasi where ozone went above the permissible limit before lockdown and during the last quarter of the year 2020. The study also shows that air pollution in the study area is mostly caused by $PM_{2.5}$ as it is the one the one that goes beyond the CPCB permissible limit. The study also confirms that the measures put in place by the government to control air pollution are working effectively as there is great improvement in the concentration of the above pollutants since 2016.

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