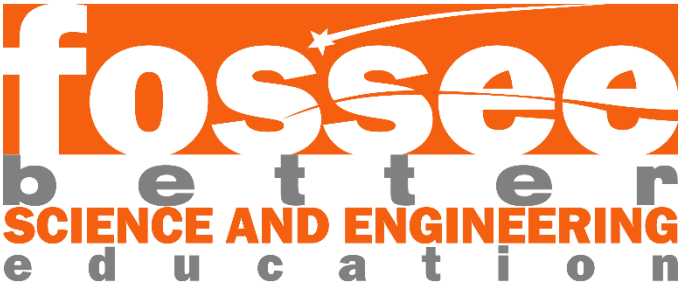

FOSSEE Summer Fellowship Report

On

Quantum GIS (QGIS)

Submitted by

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Under the Guidance of

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1. ACKNOWLEDGEMENT

I would like to express my gratitude to IIT-Bombay and FOSSEE team for providing this platform to me for learning and exploring open source software like QGIS. As it was a virtual internship this time, I would like to extend my vote of thanks to all the members of the FOSSEE team for organizing and managing this internship so well.

I am highly indebted to Prof. Kannan Moudgalya, Professor from Department of Chemical Engineering, IIT Bombay for initiating the FOSSEE project which inspired students to learn about different open source software.

I would like to thank my mentor, Prof. Pennan Chinnasamy for guiding me throughout the project. Alone with his expert advice and mentorship, he also took into consideration our views and thoughts. He was always approachable whenever I needed and always gave me innovative ideas to learn and incorporate new concepts to my project.

I would also like to express my deepest gratitude to Dr. Snehalatha Kaliappan for guiding me throughout the project duration. She helped me a lot with the scripts of spoken tutorials. Right from the starting of the internship, not only she motivated me to perform better but also appreciated my efforts. I am very grateful to her for her constant support and help.

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Lastly, I would like to thank all the faculty members and FOSSEE team for giving me this opportunity to learn new things and making this a memorable journey for me.

With Regards,

Zeel Shah,

CEPT University, Ahmedabad.

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4. GIS

4.1. Introduction to GIS

Geographic information system (GIS) is a system for capturing, storing, analysing, and displaying spatial data. By relating such spatial data, GIS can help individuals and organizations to get a better understanding of spatial patterns and relationships. [1]

4.2. Need of GIS

- Data Visualisation
- Spatial Data Analysis
- Identify Patterns and relationships

4.3. Applications of GIS

- Mapping and visualisation
- Transport analysis
- Environmental Impact analysis
- Hotspot analysis for accidents
- Urban planning
- Disaster Management
- Navigation
- Surveying
- Governance…...and much more

Figure 1 : GIS Applications [26]

5. QGIS

5.1. Introduction to QGIS

QGIS stands for **Quantum GIS.** It is a user friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License.). It runs on Linux, Unix, Mac OSX, Windows and Android and supports numerous vector, raster, and database formats and functionalities. [2]

Figure 2: QGIS Logo [27]

It allows users to analyse and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports both raster and vector layers; vector data is stored as either point, line, or polygon features. Rasters are made up of pixels based on their spatial and temporal resolutions.

QGIS can be integrated with other open-source GIS packages, including PostGIS, GRASS GIS, and MapServer. Plugins written in Python or C++ extend QGIS's capabilities. Plugins can be geocode using the Google Geocoding API and can perform geoprocessing functions similar to those of the standard tools found in ArcGIS, and thus can interact with PostgreSQL/PostGIS, SpatiaLite and MySQL databases. [3]

I have used QGIS version 3.12 for this project, which was launched on 21st February, 2020.

5.2. QGIS features used in the present study

- Raster Analysis
- Vector Analysis
- QGIS plugins for GEE

IMPACT OF COVID19 LOCKDOWN ON AIR QUALITY FOR INDIA

6. COVID 19

6.1. What is COVID 19?

Coronavirus disease 2019 (COVID-19) is defined as illness caused by a novel coronavirus now called **severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; formerly called 2019-nCoV).** It was first identified amid an outbreak of respiratory illness cases in Wuhan City, Hubei Province, China on December 31, 2019. On March 11, 2020, the COVID-19 was declared as a global pandemic. [4]

6.2. COVID 19 and India

The first case of COVID-19 in India, was reported on 30th January 2020 [5]. To overcome the situation, the PM Narendra Modi, announced a lockdown for 21 days on 24th March, which was then followed by three more lockdowns of 19 days, 14 days and 14 days respectively. From 1 June, the government announced three unlock phases (barring the containment zones).

The total number of cases before the lockdown **(i.e. on 24th March) were 564** cases [22] and at the end of 4th lockdown **(i.e. on 31st May) were 1,73,763** cases [23]. At the end of the 4th lockdown, India had the largest number of confirmed cases in Asia, and the fourth highest number in the world.

6.3. Why do we need to study air quality during the lockdown period?

- It is very important to keep a track on the air quality, as it may not only have short-term effects but can also long term effects on the health of the people.
- The health of people with heart or respiratory conditions is majorly affected by air pollution.
- Due to the lockdown, the decrease in traffic and shutting down of industrial units may help us to find out the possible sources of the air pollutant.
- The following two statements proves that it is very important to study and analyse the change in air quality during this lockdown, so that we can take preventive measures beforehand.

“The evidence we have is pretty clear that people who have been living in places that are more polluted over time, that they are more likely to die from coronavirus.”

- Aaron Bernstein, the director of the Center for Climate, Health, and Global Environment at Harvard University. [6]

“We have been talking about the possibility of airborne transmission and aerosol transmission as one of the modes of transmission of COVID-19.”

- Maria Kerkhove, technical lead on the COVID-19 pandemic at the WHO [7]

7. PROBLEM STATEMENT

7.1. India’s past performance w.r.t air quality

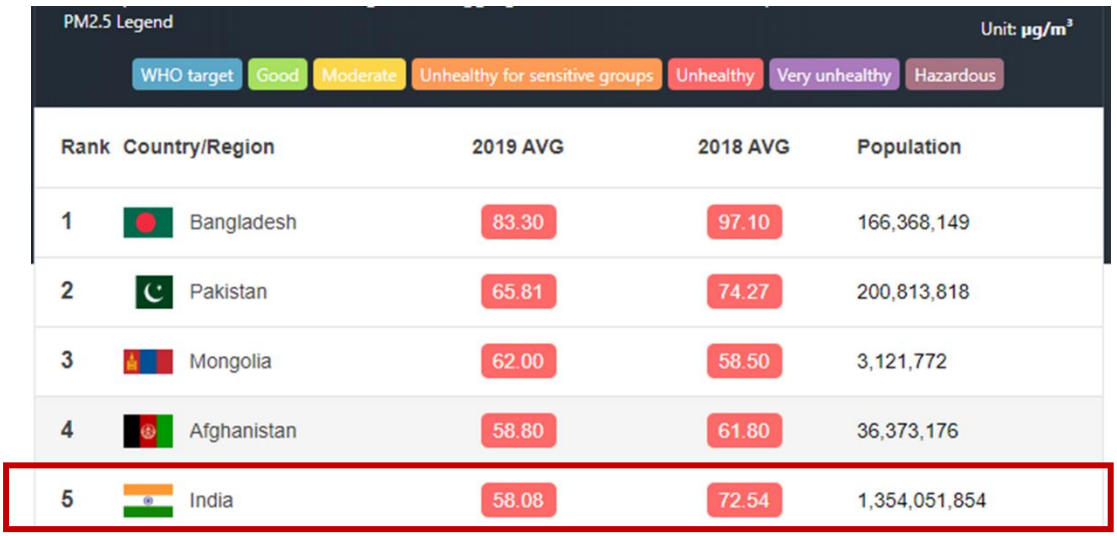
India was the 5th most polluted country in 2019, with Ghaziabad in the National Capital Region ranked as the most polluted city in the world, according to a global compilation of PM 2.5 particulate pollution data by IQAir, a company that primarily works on air filtration. [8]

From the list of top most polluted 10 cities, six cities were located in India, with Delhi at the 5th position in the most polluted cities in the world. Delhi being the capital of India, it is very worrisome, and strict control actions are very important to improve the air quality.

7.2. Problem Statement

Thus, the poor air quality makes it very important to know the source of air pollutants, so that we can take precautionary measures beforehand. This study will help us to understand the current scenario

of air pollutants, changes occurred in them due to lockdown and to identify their possible sources. To support the findings, interactive maps and statistical graphs are also produced.



Rank	Country/Region	2019 AVG	2018 AVG	Population
1	Bangladesh	83.30	97.10	166,368,149
2	Pakistan	65.81	74.27	200,813,818
3	Mongolia	62.00	58.50	3,121,772
4	Afghanistan	58.80	61.80	36,373,176
5	India	58.08	72.54	1,354,051,854

Figure 3: India's ranking in most polluted countries of the world. [28]

8. AIM and OBJECTIVES

8.1. Aim

To study the impact of the lockdown on the air quality, during the Covid19 pandemic, through analysing the change in major air pollutants, for before and after the lockdown period for India.

8.2. Objectives

- To study and analyse the change in major air pollutants (such as SO_2, NO_2, CO, O^3, PM2.5 and PM10) at their respective hotspots.
- To make interactive maps and statistical graphs, to support the findings for the interval period of, before the lockdown (1st of March, 2020) to the end of the 4th Lockdown (31st of May, 2020).

9. DATASETS USED

9.1. Time interval of lockdown

On 22 March, India observed a 14-hour voluntary public curfew at the instance of the prime minister Narendra Modi. It was followed by mandatory lockdowns in COVID-19 hotspots and all major cities.

- **LOCKDOWN 1**: 25 March 2020 – 14 April 2020 (21 days)
- **LOCKDOWN 2**: 15 April 2020 – 3 May 2020 (19 days)
- **LOCKDOWN 3**: 4 May 2020 – 17 May 2020 (14 days)
- **LOCKDOWN 4**: 18 May 2020 – 31 May 2020 (14 days)

INTRA-STATE RELAXATIONS were given in Lockdown 3 while **INTER-STATE RELAXATIONS** were given in Lockdown 4. [9]

9.2. Time interval chosen for the study

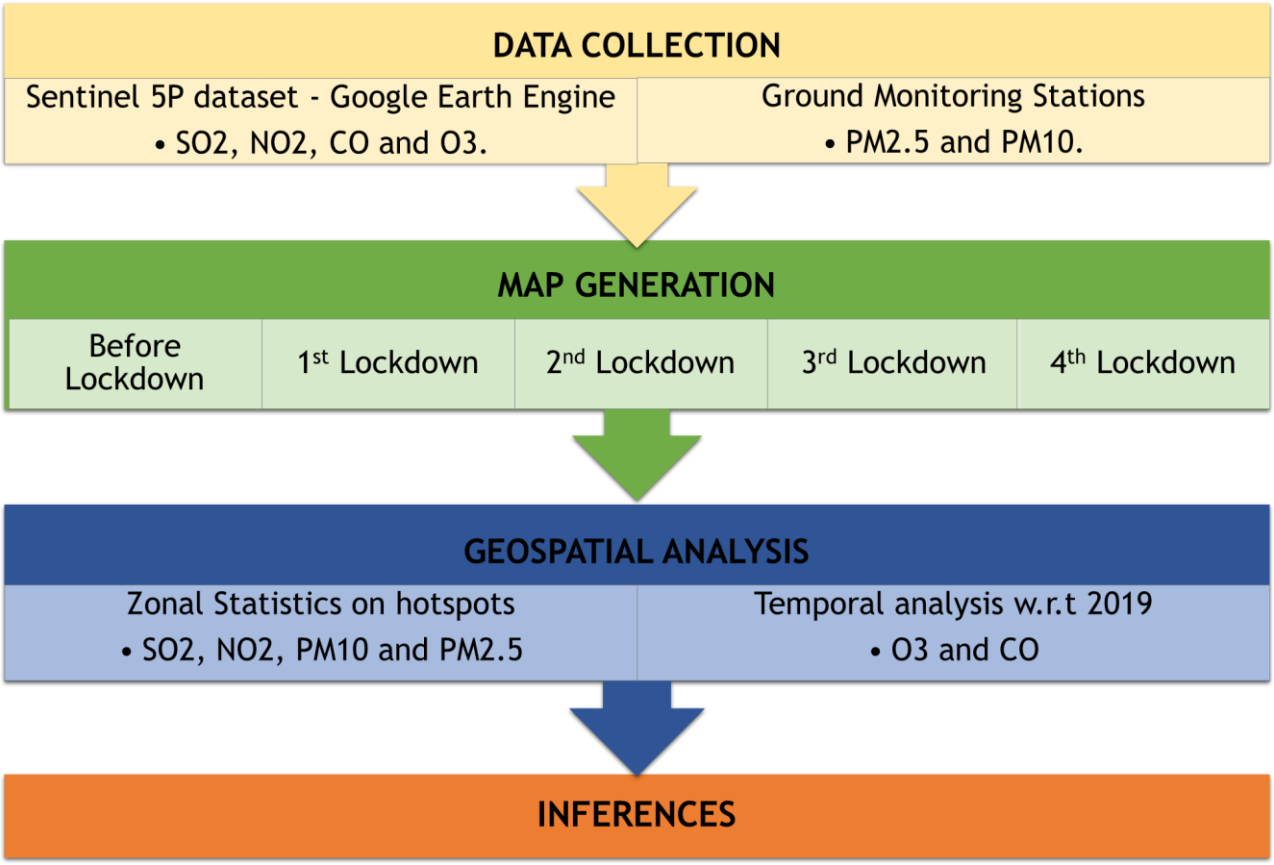
Based on the coverage of the data for the country and the quality of the data, the time intervals may vary in each lockdown period.

•**BEFORE LOCKDOWN** : 01 March 2020 – 07 March 2020
•**LOCKDOWN 1**: 01 April 2020 – 10 April 2020
•**LOCKDOWN 2**: 20 April 2020 – 30 April 2020
•**LOCKDOWN 3**: 12 May 2020 – 17 May 2020
•**LOCKDOWN 4**: 21 May 2020 – 27 May 2020

9.3. Detailed information of the datasets

Parameter	Units	Satellite/ Monitoring Station	Source	Spatial Resolution	Time Interval	Link
SO_2	mol/m^2	Sentinel-5P	Google Earth Engine	7 x 3.5 km^2	One day	https://developers.google.com/s/results/earth-engine/datasets/
NO_2	mol/m^2	Sentinel-5P	Google Earth Engine	7 x 3.5 km^2	One day	https://developers.google.com/s/results/earth-engine/datasets/
CO	mol/m^2	Sentinel-5P	Google Earth Engine	7 x 3.5 km^2	One day	https://developers.google.com/s/results/earth-engine/datasets/
Ozone	mol/m^2	Sentinel-5P	Google Earth Engine	7 x 3.5 km^2	One day	https://developers.google.com/s/results/earth-engine/datasets/
PM 2.5	ug/m^3	Monitoring Station	Central Pollution Control Board	--	One day	https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing
PM 10	ug/m^3	Monitoring Station	Central Pollution Control Board	--	One day	https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing

10. METHODOLOGY



10.1. Code used in Google Earth Engine

```
var collection = ee.ImageCollection('COPERNICUS/S5P/NRTI/L3_SO2')
                                    .select('SO2_column_number_density')
                                    .filterDate('2020-03-01', '2020-03-07');
var band_viz = {
          min: 0.0,
          max: 0.0005,
          palette: ['black', 'blue', 'purple', 'cyan', 'green', 'yellow', 'red'] };

Map.addLayer(collection.mean(), band_viz, 'S5P SO2');

var roi = ee.FeatureCollection("users/shahzeel999/India");
Map.addLayer(roi,{ }, 'India');

Export.image.toDrive({
          image: collection,
          description: 'Before_SO2',
          scale: 2000,
          region: roi  });
```

10.2. Data from Ground Control Monitoring Stations

Figure 4: Dashboard of Central Control Room for Air Quality Management - All India [29]

The above shown portal gives us the data for major air pollutants across India. We can get the data in tabular, excel or graph format for any time period for a given monitoring station. **As the data for PM10 and PM2.5 is not available in Google Earth Engine, the ground controlled monitoring stations data was used.** Using the data, a master excel sheet was generated for the project which included the daily data of PM2.5 and PM10 with their corresponding ground control station as shown in the figure below. The data was geocoded by adding longitude and latitude to excel, for further analysis in QGIS.

	A	B	C	D	E	F	G	H	I	J	K	L
1	STATE	CITY	STATION	LONGITUDE	LATITUDE	STATUS	01-01-2020	02-01-2020	03-01-2020	04-01-2020	05-01-2020	06-01-20
2		Amaravati	Secretariat, Amaravati - APPCB	80.5181667	16.5150833	Delay	87.32	65.39	61.32	39.48	56.52	63.
3		Rajamahendravaram	Anand Kala Kshetram, Rajamahendravaram - APPCB	81.7363176	16.9872867	Live	80.83	66.62	67.11	39.33	50.96	72.
4	Andhra Pradesh	Tirupati	Tirumala, Tirupati - APPCB	79.35	13.67	Live	26.85	13.28	-	55.88	38.64	29.
5		Vijayawada	PWD Grounds, Vijayawada - APPCB	80.627767	16.507014	Inactive	0	0	0	0	0	
6		Visakhapatnam	GVM Corporation, Visakhapatnam - APPCB	83.3	17.72	Live	103.61	92.51	90.22	48.93	43.23	8
7	Assam	Guwahati	Railway Colony, Guwahati - APCB	91.78063	26.181742	Live	191.37	102.28	102.37	132.18	136.95	165.
8		Gaya	Collectorate, Gaya - BSPCB	84.9994	24.7955	Live	0	0	0	0	0	
9			SFTI Kusdihra, Gaya - BSPCB	84.982348	24.762518	Live	-	-	-	-	-	-
10		Hajipur	Industrial Area, Hajipur - BSPCB	85.2459	25.697189	Live	-	-	-	-	-	-
11		Muzaffarpur	Muzaffarpur Collectorate, Muzaffarpur - BSPCB	85.3647	26.1209	Live	0	0	0	0	0	
12	Bihar	Patna	DRM Office Danapur, Patna - BSPCB	85.043586	25.586562	Live	-	-	-	-	-	-
13			Govt. High School Shikarpur, Patna - BSPCB	85.227158	25.592539	Live	-	-	-	-	-	-
14			IGSC Planetarium Complex, Patna - BSPCB	85.1376	25.5941	Inactive	0	0	0	0	0	
15			Muradpur, Patna - BSPCB	85.147382	25.619651	Live	269.71	302.52	184.67	108.14	109.4	148.
16			Rajbansi Nagar, Patna - BSPCB	85.113666	25.599486	Live	263.65	242.5	181.31	106.07	105.85	179.
17			Samanpura, Patna - BSPCB	85.085624	25.596727	Live	278.04	263.55	190.44	105.25	98.91	16
18	Chandigarh	Chandigarh	Sector-25, Chandigarh - CPCC	76.762879	30.751462	Live	133.02	103.44	95.45	109.91	104.21	6
19		Delhi	Alipur, Delhi - DPCC	77.15301	28.815329	Live	283.79	304.96	312.21	321.48	252.3	217.
20			Anand Vihar, Delhi - DPCC	77.316032	28.646835	Live	460.72	472.6	492.54	361.17	315.02	289.
21			Ashok Vihar, Delhi - DPCC	77.181665	28.695381	Live	491.04	482.78	341.08	399.48	288.48	266.
22			Aya Nagar, Delhi - IMD	77.1099364	28.4706914	Live	402.03	227.78	274.14	237.7	220.23	204.
23			Bawana, Delhi - DPCC	77.051074	28.776200	Live	543.33	411.36	282.41	435.91	281.12	29

Figure 5: Master Excel sheet for PM10 and PM2.5

11. Air Pollutants from Satellite Data

11.1. Sulphur Dioxide (SO_2)

11.1.1. Source: The primary reason for India's high emission of SO_2 is the expansion of coal-based electricity generation over the past decade. Other sources include industrial processes such as extracting metal from ore, natural sources such as volcanoes, and locomotives, ships and other vehicles and heavy equipment that burn fuel with high sulphur content. [10]

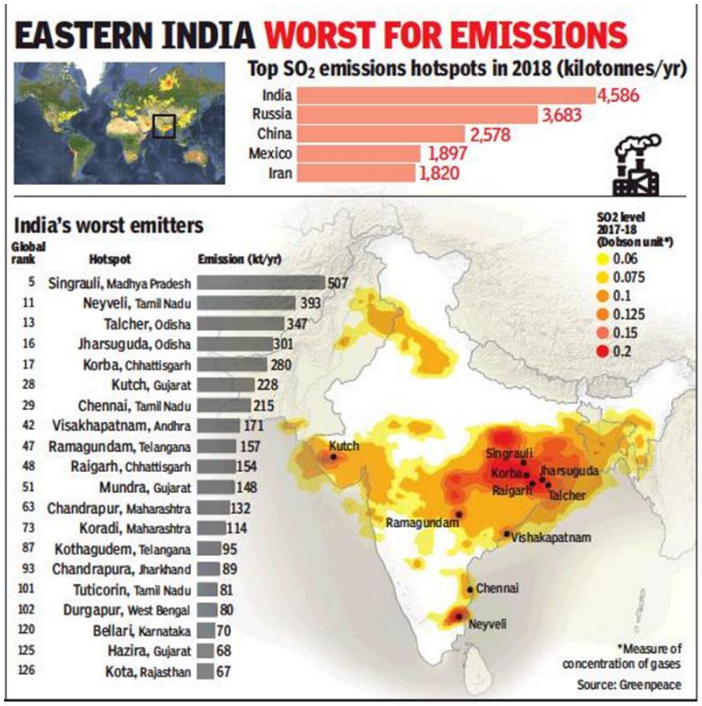


Figure 6: Hotspots for SO2 emission in India [30]

11.1.2. Impact of SO_2: A major consequence of increased sulphur dioxide in the atmosphere is acid rain — where sulphur dioxide mixes with rainwater to create sulphuric acid rain. The effects of acid rain include stunting and eventual death of trees, pollution and death of water bodies, and corrosion of marble and limestone. [25]

As shown in the figure, the data for SO_2 is for 2018, it is very important to check the scenario for 2020.

Looking at the hotspots in the map of SO2 (before the lockdown), the coal-based power plants were plotted there and is shown in the figure below.

HOTSPOT 1: Villupuram, Cuddalore, Vridhachalam (Tamil Nadu)

HOTSPOT 2: Singrauli (M.P), Sonbhadra (U.P), Surguja (Chhattisgarh)

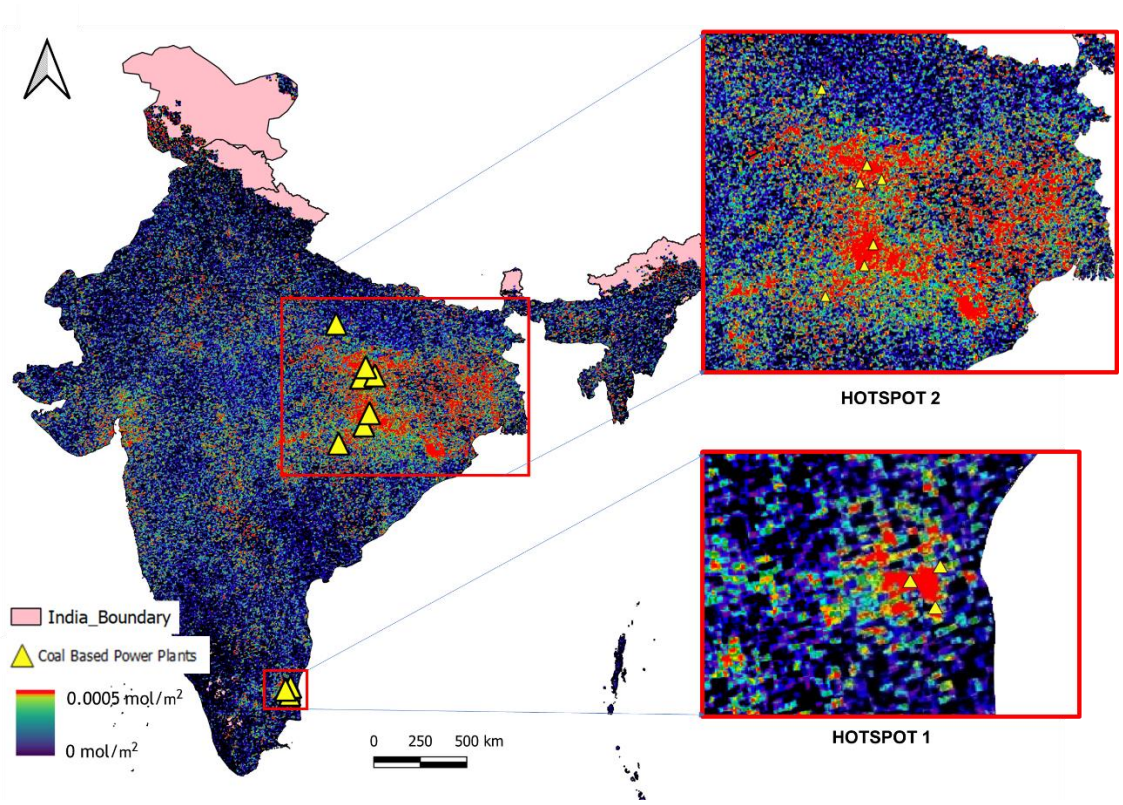


Figure 7: It shows the location of Coal power plants on the hotspots of SO2 emission

11.1.3. Maps and graph

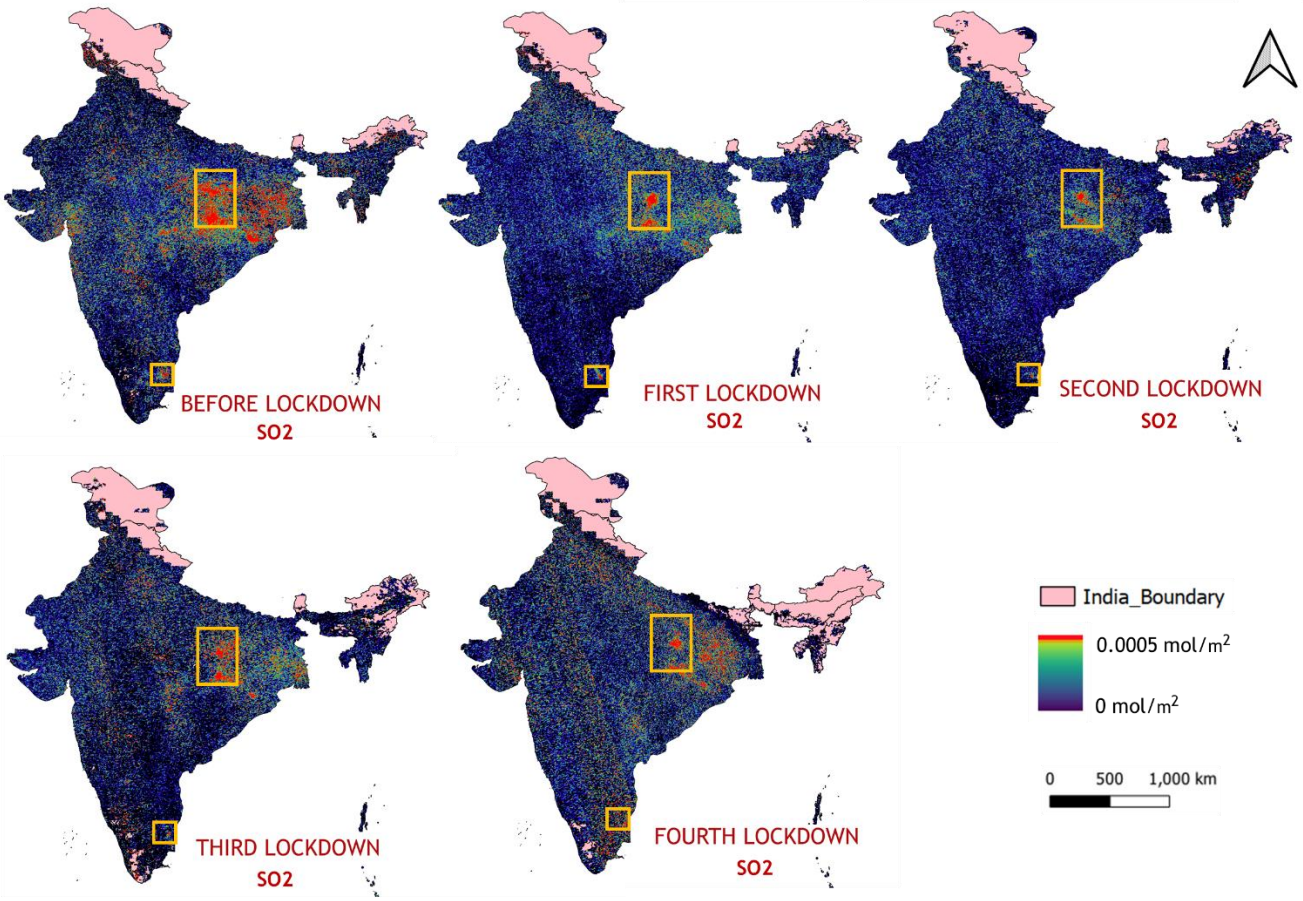
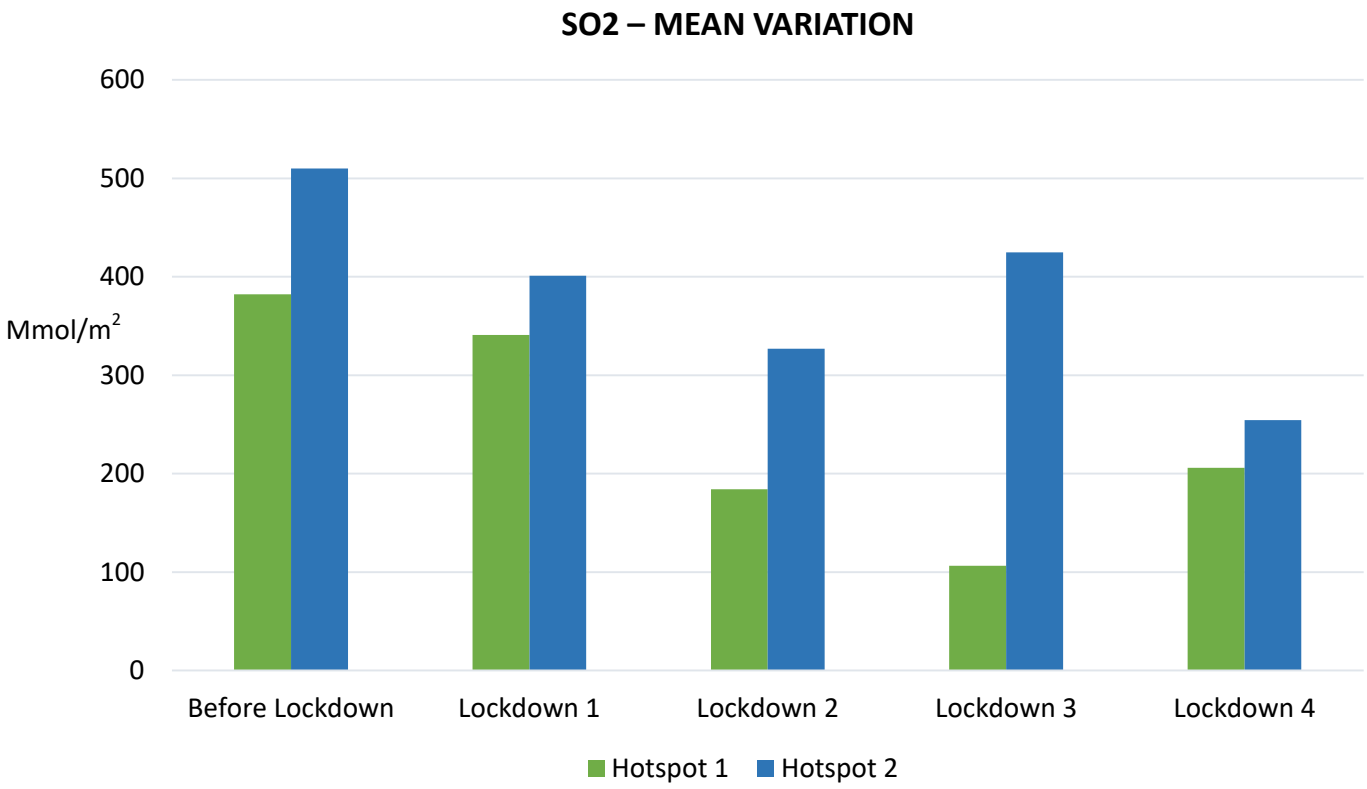


Figure 8: Variation of SO2 during various stages of lockdown.



11.1.4. Inferences:

- The location of coal power plants were almost at the hotspots identified on SO2 map, giving an indication of possibility of coal combustion being an primary source for SO2.
- A gradual decrease is observed in the values of SO2 at Hotspot1 till the 3rd lockdown.
- A sudden increase in values may be the resultant of the relaxations given at Hotspot1.
- A gradual decrease is also observed in values of SO2 at Hotspot2 till the 2nd lockdown, along with a sudden fluctuation in values in 3rd and 4th lockdown.
- **Change in SO2 (Before lockdown to 4th lockdown):** **-46.08%** at hotspot1 and **-50.14%** at hotspot2.

11.2. Nitrogen Dioxide (NO2)

11.2.1. Source:

The main source of nitrogen dioxide resulting from human activities is the combustion of fossil fuels (coal, gas and oil) especially fuel used in cars. It is also produced from making nitric acid, welding and using explosives, refining of petrol and metals, commercial manufacturing, and food manufacturing. [11]

11.2.2. Impact of NO2:

The main health effect of nitrogen dioxide is on the respiratory system. Inhalation of nitrogen dioxide by children increases their risk of respiratory infection and may lead to poorer lung function in later life. Nitrogen dioxide forms acids in the presence of moisture and these can be corrosive to building materials at high concentrations. [11]

Looking at the hotspots in the map of NO2 (before the lockdown), the coal-based power plants were plotted there and is shown in the figure below.

HOTSPOT 1: Delhi, Ghaziabad and Gautam Buddha Nagar (U.P), Faridabad (Haryana).

HOTSPOT 2: Sidhi and Sonbhadra (M.P), Korba, Bilaspur, Raipur, Durg, Janjgir, Rajgarh, Jangir-Champu, Jharsuguda and Sambalpur (Chhatisgarh).

HOTSPOT 3: Bankur, Bardhhaman and Birkhum (West Bengal), Jamtara, Dhanbad and Bokara (Jharkhand)

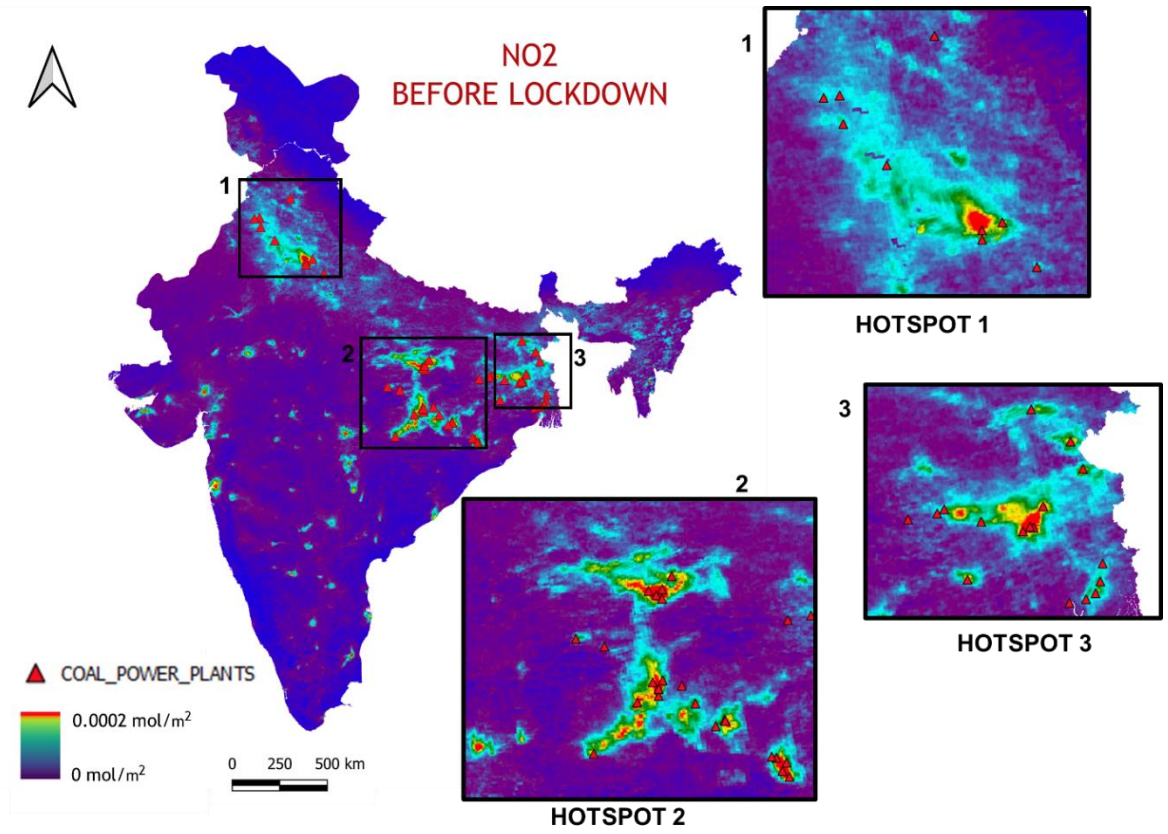


Figure 9: It shows the location of Coal power plants on the hotspots of NO2 emission

11.2.3. Maps and graph

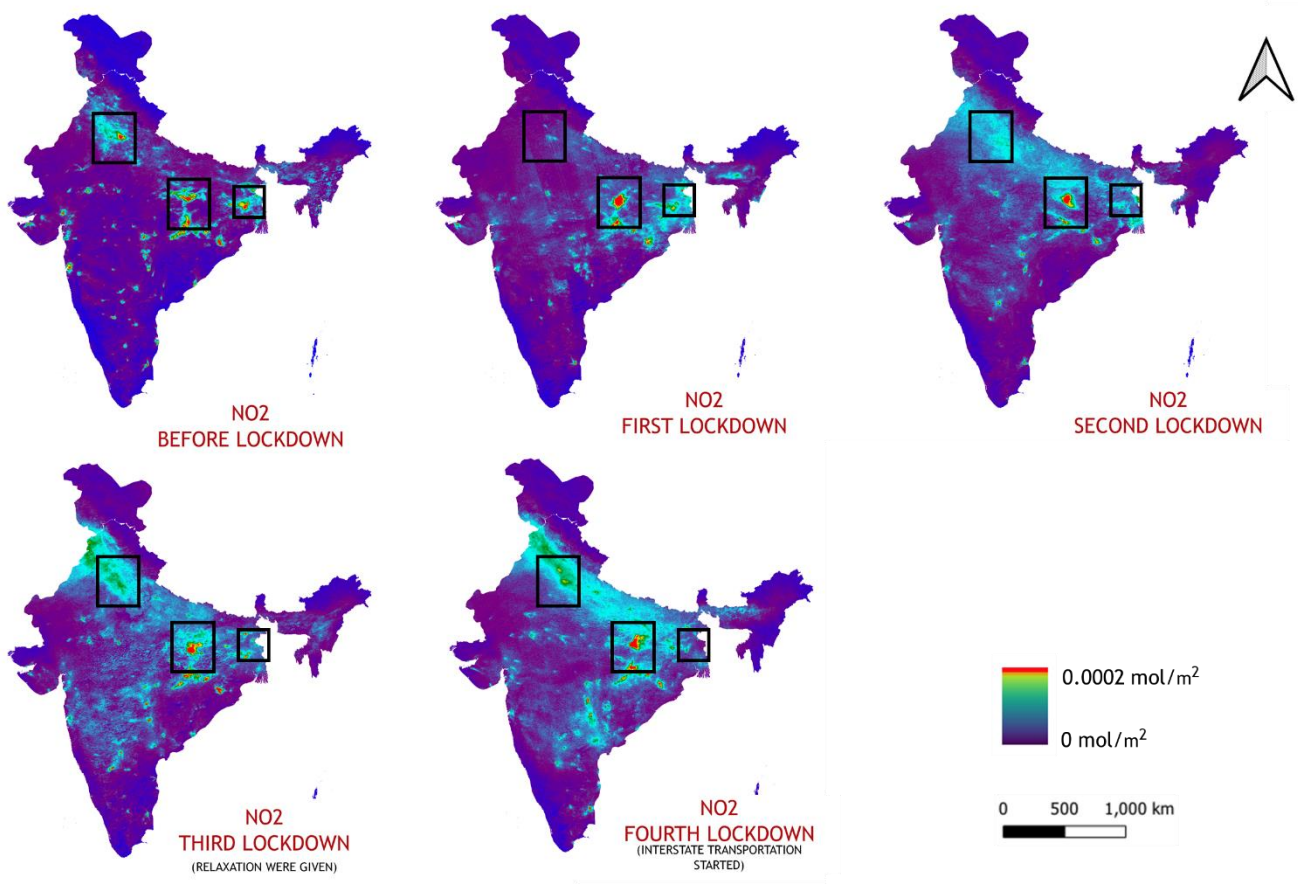
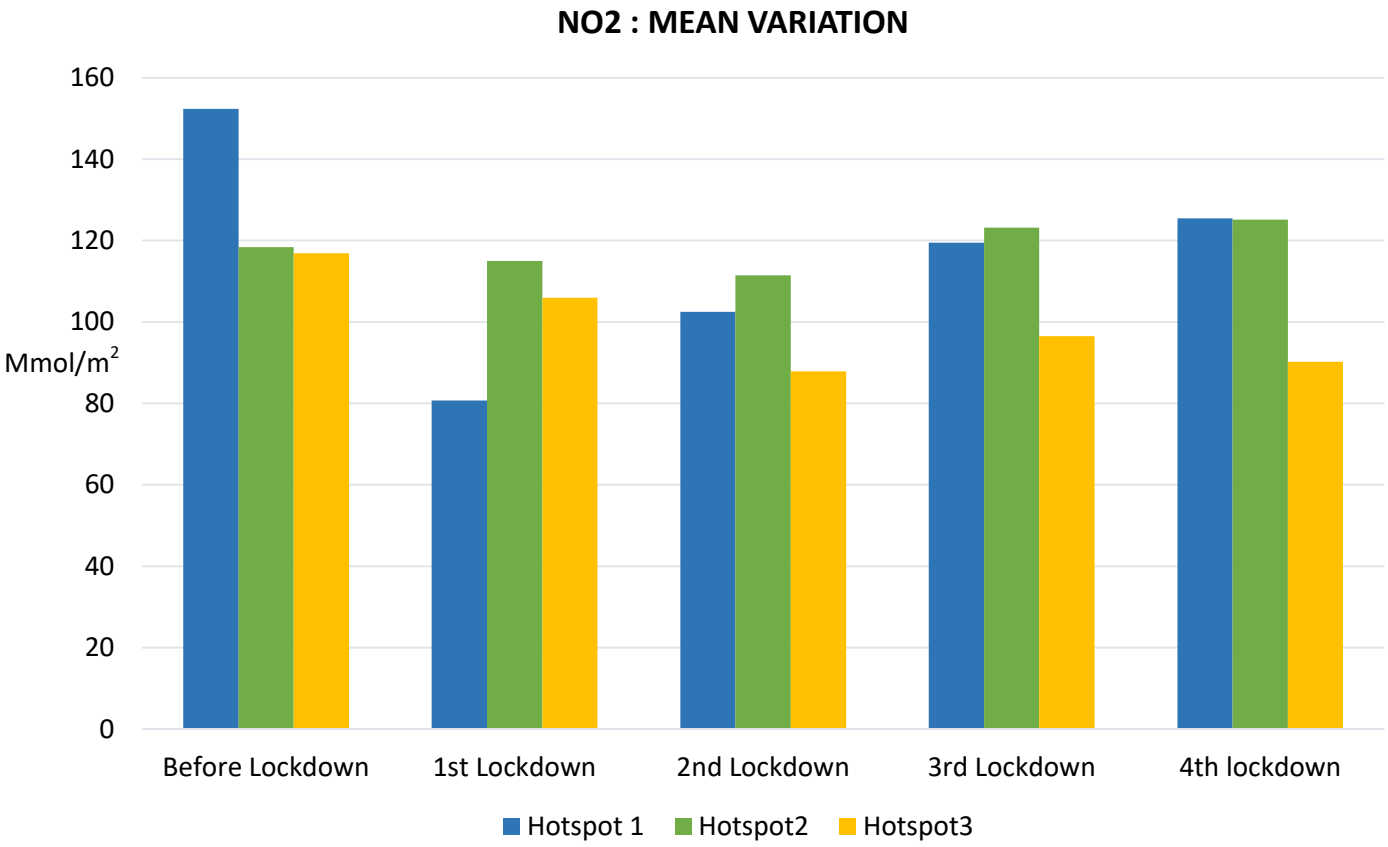


Figure 10: Variation of NO2 during various stages of lockdown



11.2.4. Inferences

- The location of coal power plants were almost at the hotspots identified on NO2 map, giving an indication of possibility of coal combustion being an primary source for NO2.
- A gradual decrease is observed in the values of NO2 at Hotspot1 in the 1st lockdown, while the values kept increasing slowly till the 4th lockdown.
- A gradual decrease is also observed in values of NO2 at Hotspot2 till the 2nd lockdown, along with a minor increase in values at 3rd and 4th lockdown, leading to higher value at 4th lockdown than values at before lockdown.
- A gradual decrease is also observed in values of NO2 at Hotspot3 till the 3rd lockdown, along with a minor fluctuation in values in 3rd and 4th lockdown.
- **Change in NO2 (Before lockdown to 4th lockdown):** **-17.64%** in hotspot1, **5.74%** in hotspot2 and **-22.77%** in hotspot3.

11.3. OZONE (O3)

11.3.1. Source:

Ozone occurs in two layers of the atmosphere. The layer closest to the Earth's surface is the troposphere. Here, ground-level or "bad" ozone is an air pollutant that is harmful to breathe and it damages crops, trees and other vegetation. It is a main ingredient of urban smog. It is created by chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOC). This happens when pollutants emitted by cars, power plants, industrial boilers, refineries, chemical plants, and other sources chemically react in the presence of sunlight. [12]

The troposphere generally extends to a level about 6 miles up, where it meets the second layer, the stratosphere. The stratosphere or "good" ozone layer extends upward from about 6 to 30 miles and protects life on Earth from the sun's harmful ultraviolet (UV) rays. [13]

11.3.2. Impact of Ozone:

Ozone in the air we breathe can harm our health. People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. [12]

The data we get from Google Earth Engine for Ozone is the total ozone level in the atmosphere.

- From April to August in Indian subcontinent, due to meteorological factors, a usual high is observed in O3. This leads in increase in amount of ozone from the period of 1st lockdown. [14]
- NO + O3=NO2+O2 [15], as levels of NO and NO2 pollutants has increased due to relaxations given, the level of ozone is also intended to decrease.

As shown below in the figure, that it's not possible to identify the hotspots of Ozone, a comparison between year 2019 and year 2020 is done for the same time interval as of the lockdown given in year 2020.

11.3.3. Maps and Graph

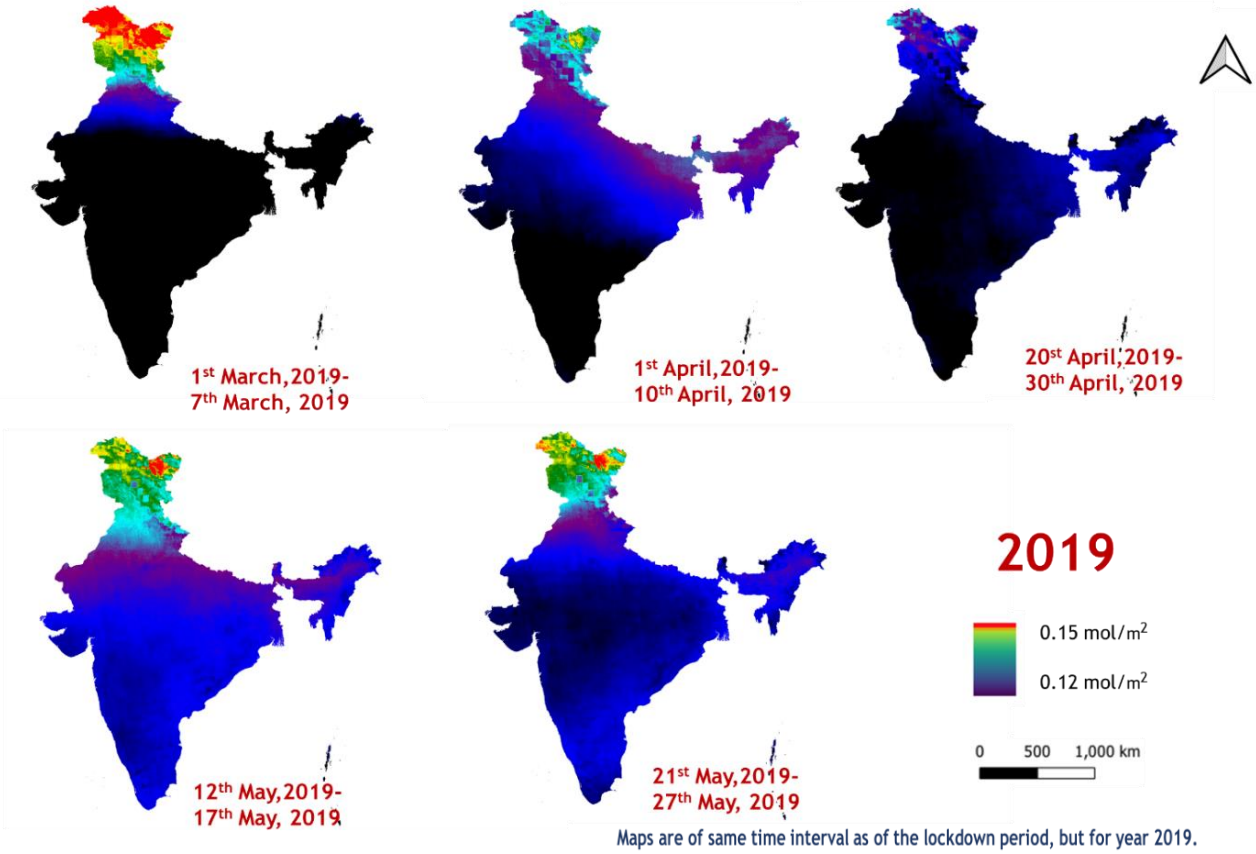


Figure 11: Variation of O3 during various stages of lockdown for year 2019.

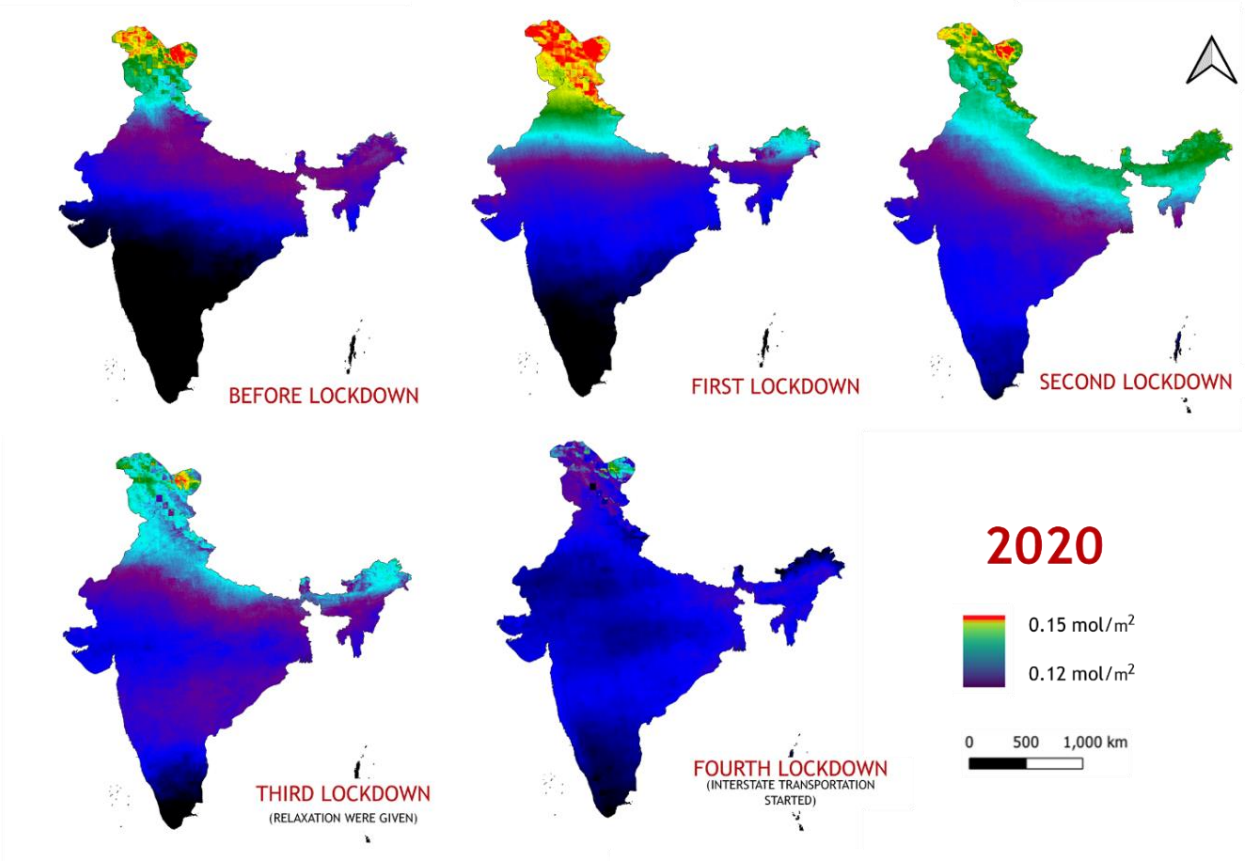
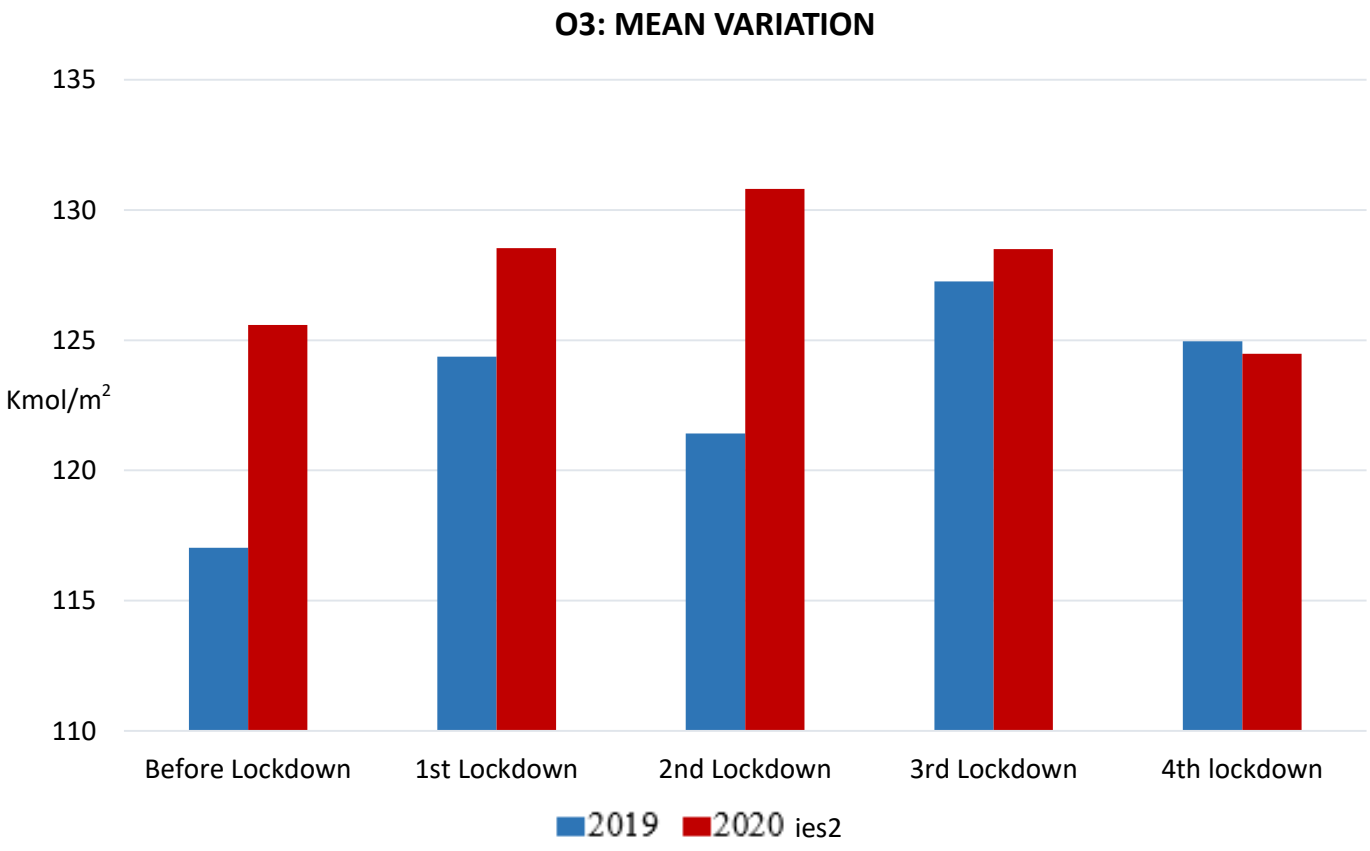


Figure 12: Variation of O3 during various stages of lockdown for year 2020.



11.3.4. Inferences

- An increasing trend is observed in India in both the years i.e. 2019 and 2020, as there is an increase in ozone in the indian subcontinent.
- As the levels of NO and NO2 has decreased in lockdown, the level of O3 has increased.
- But, as the level of NO2, NO has increased due to the relaxations given from 3rd lockdown, the level of O3 has shown a reducing trend in 2020 compared to the level of O3 in 2019.
- **Change in O3 (Before lockdown to 4th lockdown): 6.7%** in 2019, while **-0.87%** in 2020.

11.4. Carbon Monoxide (CO)

11.4.1. Source:

Other than incomplete combustion from vehicles, the major component of the CO anthropogenic emissions comes from biofuel use, which contributes 41% to the total anthropogenic emissions. The contributions from industrial, transportation and power plants sectors are estimated as 30%, 28%, and 1%, respectively. Anthropogenic CO emissions are highest over the Indo-Gangetic Plain (IGP) region and other megacities (e.g., Ahmedabad, Mumbai, Delhi, Dhaka, Kolkata, and Thiruvananthapuram). [16]

11.4.2. Impact of CO:

CO does not participate in secondary atmospheric reactions but has approximately 210 times more affinity for the haemoglobin (Hb) than oxygen (O2). The continuous exposure to the vehicular exhaust can lead to the symptoms of chronic CO intoxication, lower respiratory tract disorders such as cough, shortness of breath and pain with inspiration, blurry vision, difficulty in concentration, and confusion. [17]

11.4.3. Maps and Graph:

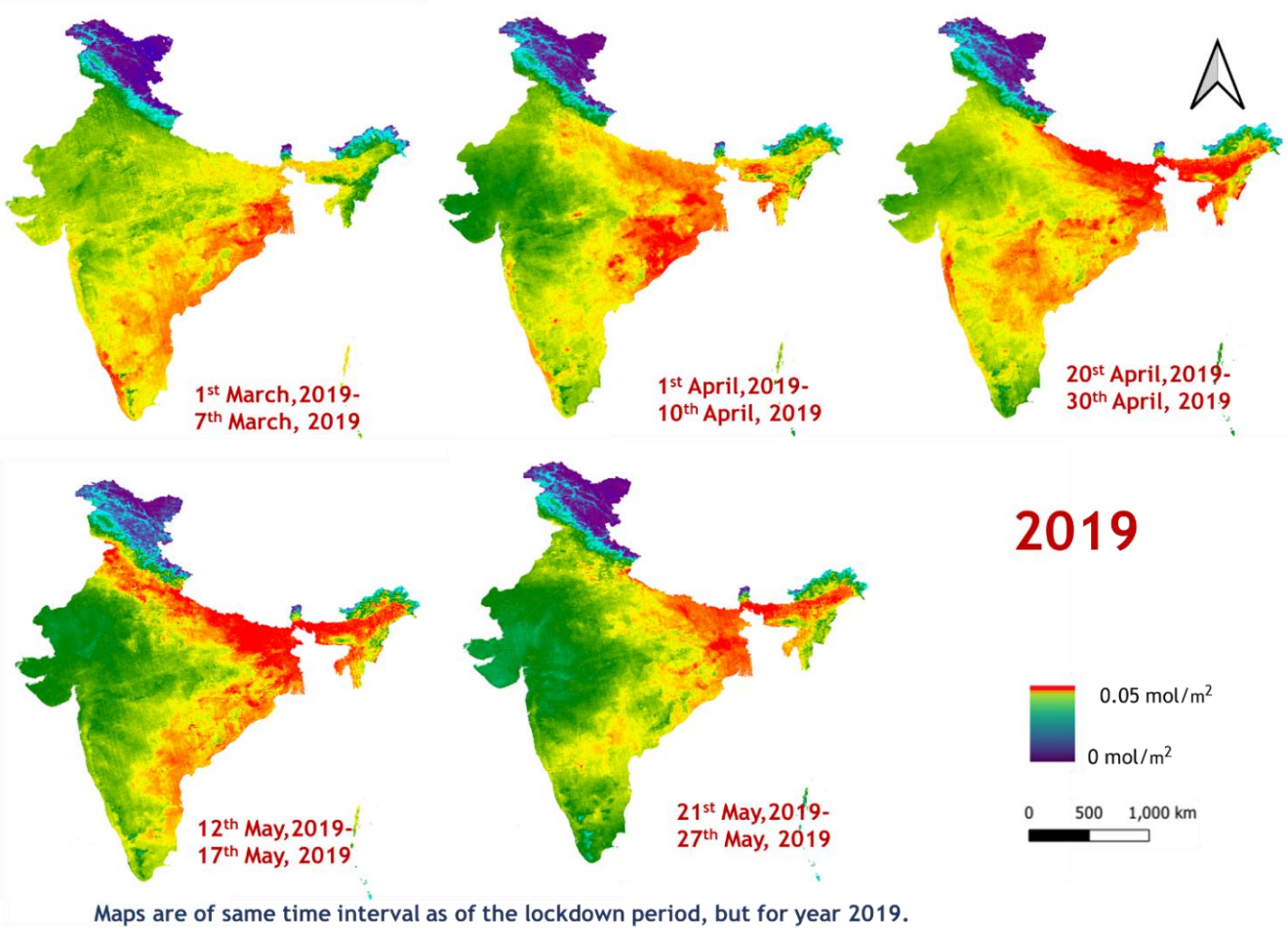


Figure 13: Variation of CO during various stages of lockdown for year 2019.

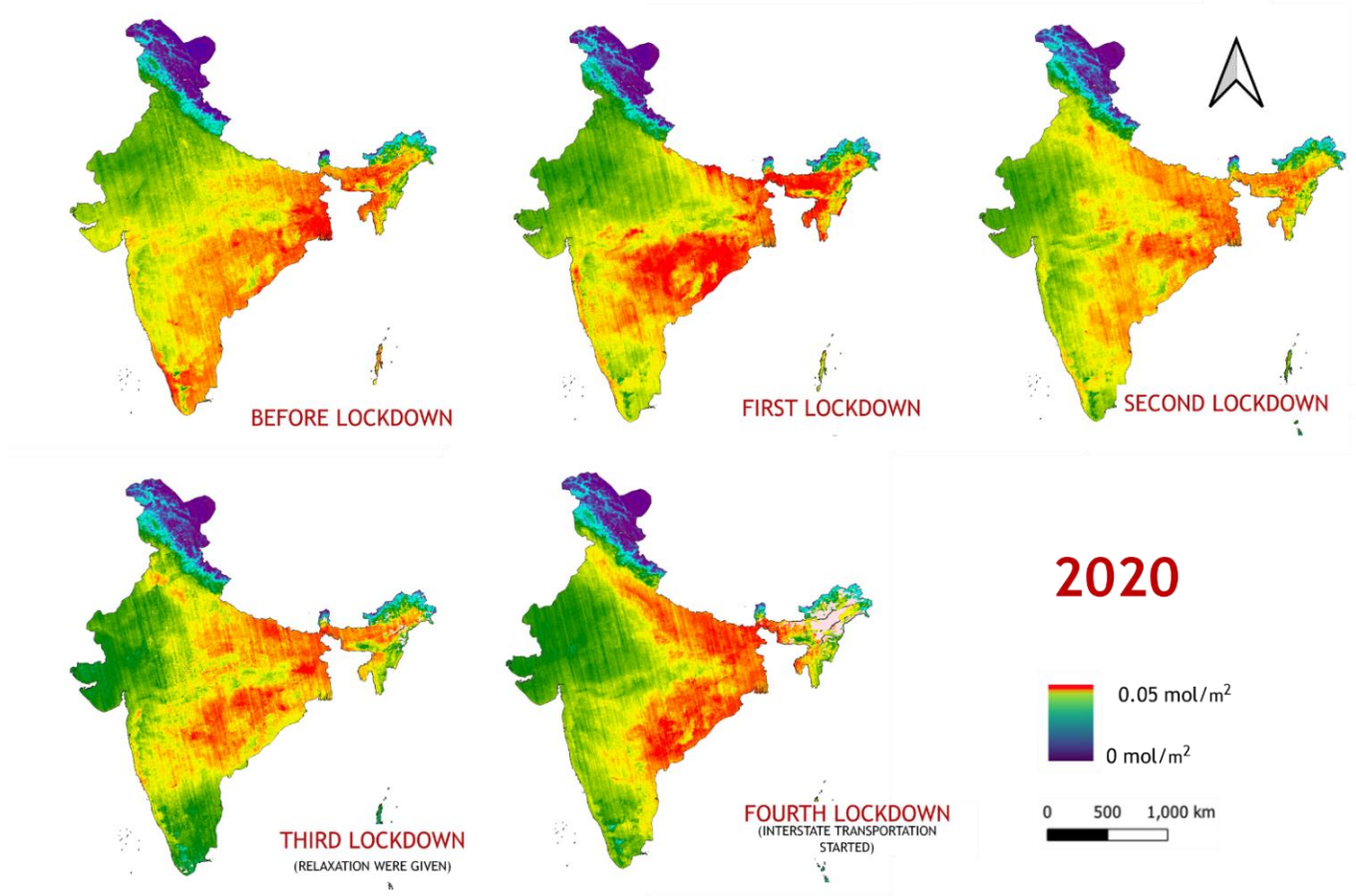
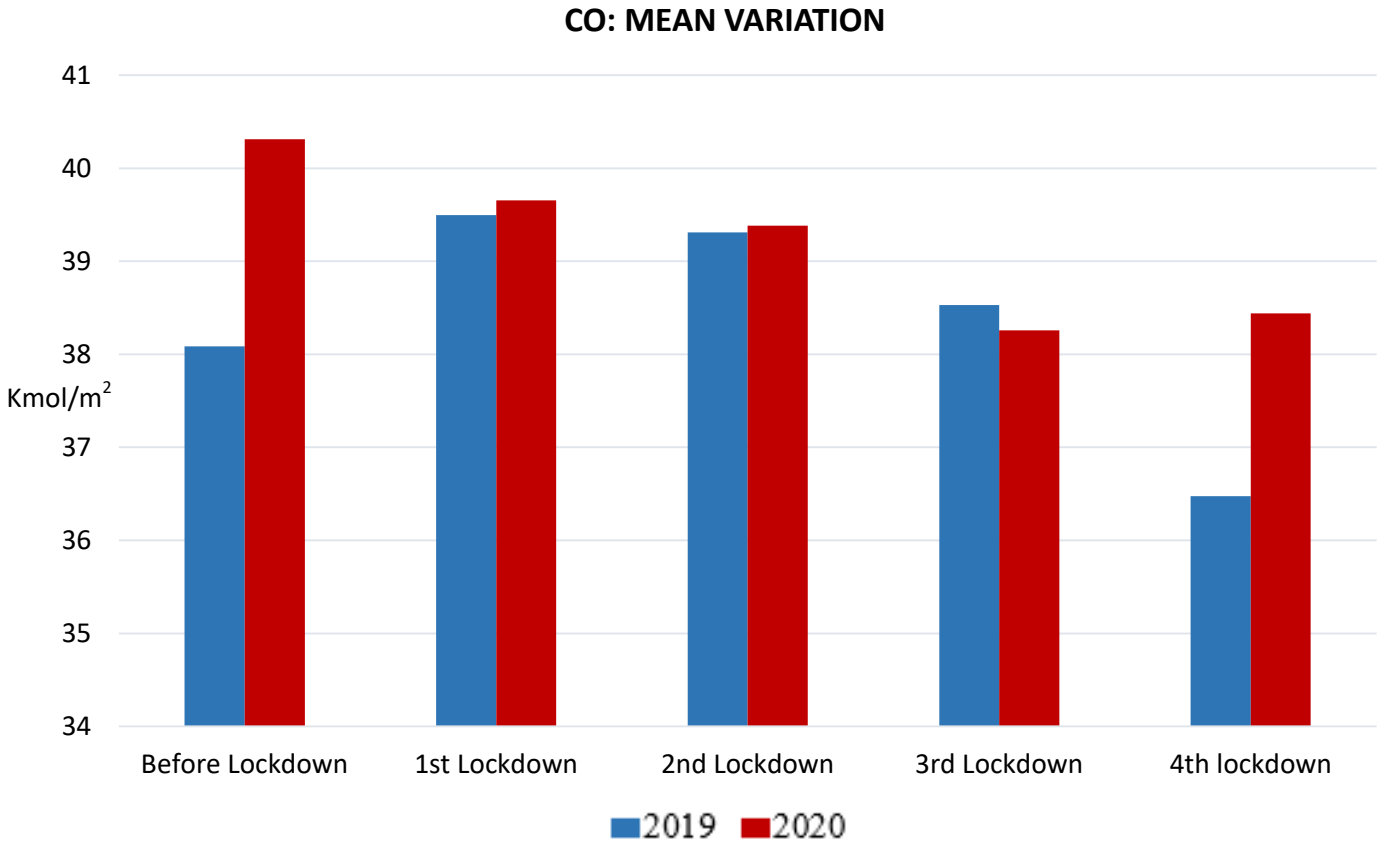


Figure 14: Variation of CO during various stages of lockdown for year 2020.



11.4.4. Inferences:

- As the major sources of CO i.e. vehicular incomplete combustion and biomass burning has reduced due to lockdown, a decrease in the value of CO is observed in year 2020 while there was an increase in CO in year 2019.
- In 2020, a minor increase is seen in the 4th lockdown, as the possible result of the given relaxations.
- Even though the values at the end of 4th lockdown are higher in 2020 than in 2019, the percentage decrease is higher in 2020 compared to 2019.
- **Change in CO (Before lockdown to 4th lockdown): -4.22%** in 2019, while **-4.64%** in 2020.

12. Air Pollutants from monitoring stations

As we can see in the figure below, that the monitoring stations are situated in a clustered pattern, the interpolation within the particular clustered area is more advisable rather than interpolating it for the whole India. So, as shown, four major cities like Delhi, Mumbai, Bangalore and Kolkata were selected, as they also have a good number of monitoring stations within the city.

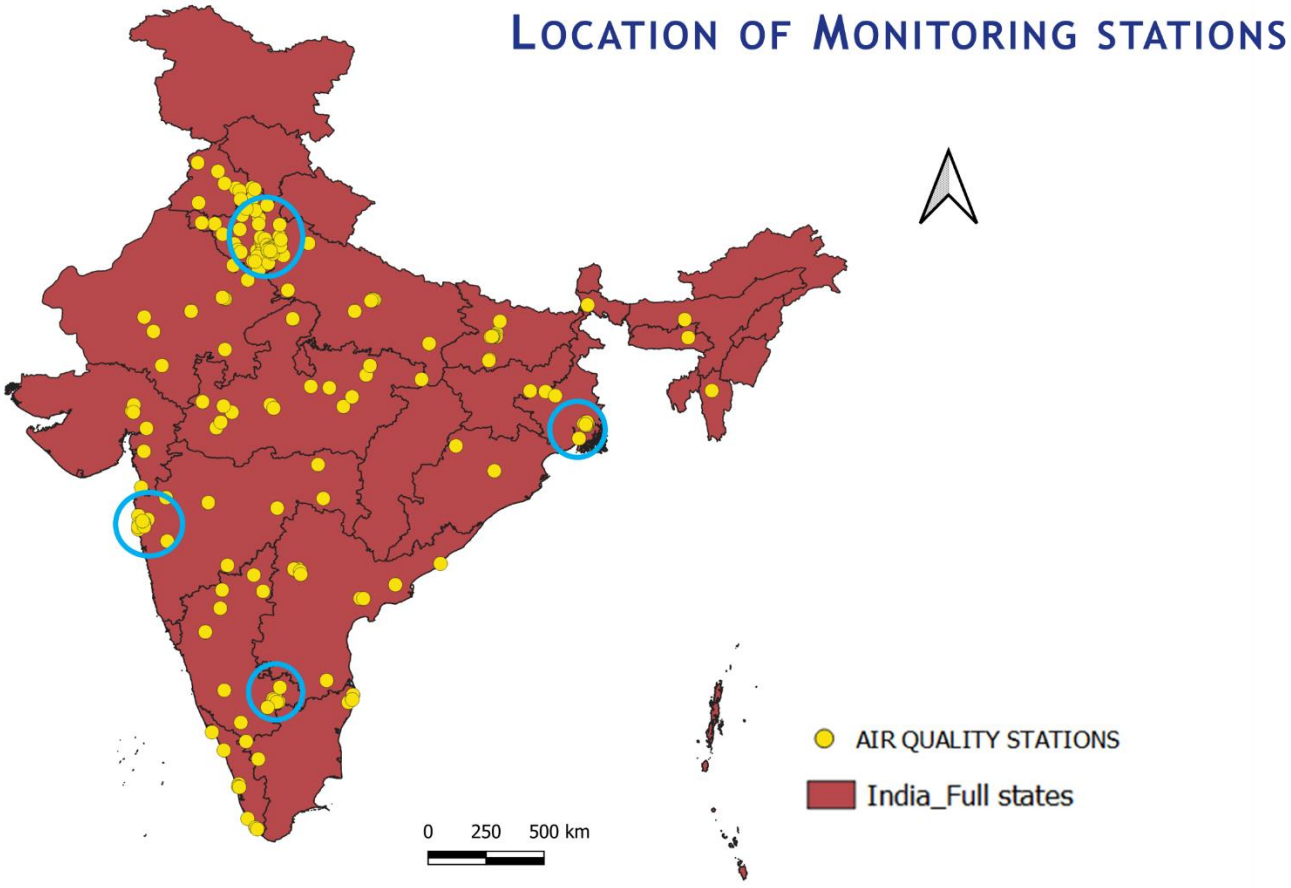


Figure 15: Location of ground monitoring stations for air quality for India

12.1. Particulate Matter 2.5 (PM2.5)

12.1.1. Source:

PM2.5 is particulate matter 2.5 micrometers or less in diameter. PM2.5 is generally described as fine particles. [18] The widths of the larger particles in the PM2.5 size range would be about thirty times smaller than that of a human hair. [19]

There are outdoor and indoor sources of fine particles. Outside, fine particles primarily come from car, truck, bus and other operations that involve the burning of fuels such as wood, heating oil or coal and natural sources. Some indoor sources of fine particles are tobacco smoke, cooking and operating fireplaces and fuel-burning space heaters. [24]

$PM_{2.5}$		
Sectors	Winters	Summers
Residential	10%	8%
Agri. Burning	4%	7%
Industry	30%	22%
Dust (soil, road, const.)	17%	38%
Transport	28%	17%
Others	11%	8%

Figure 16: Contributing sectors for PM2.5 for Delhi city [31]

12.1.2. Impact of PM2.5:

Exposure to fine particles can cause short-term health effects such as eye, nose, throat and lung irritation, coughing, sneezing, runny nose and shortness of breath. Scientific studies have linked increases in daily PM2.5 exposure with increased respiratory and cardiovascular hospital admissions, emergency department visits and deaths. [24]

12.1.3. Maps and Graph:

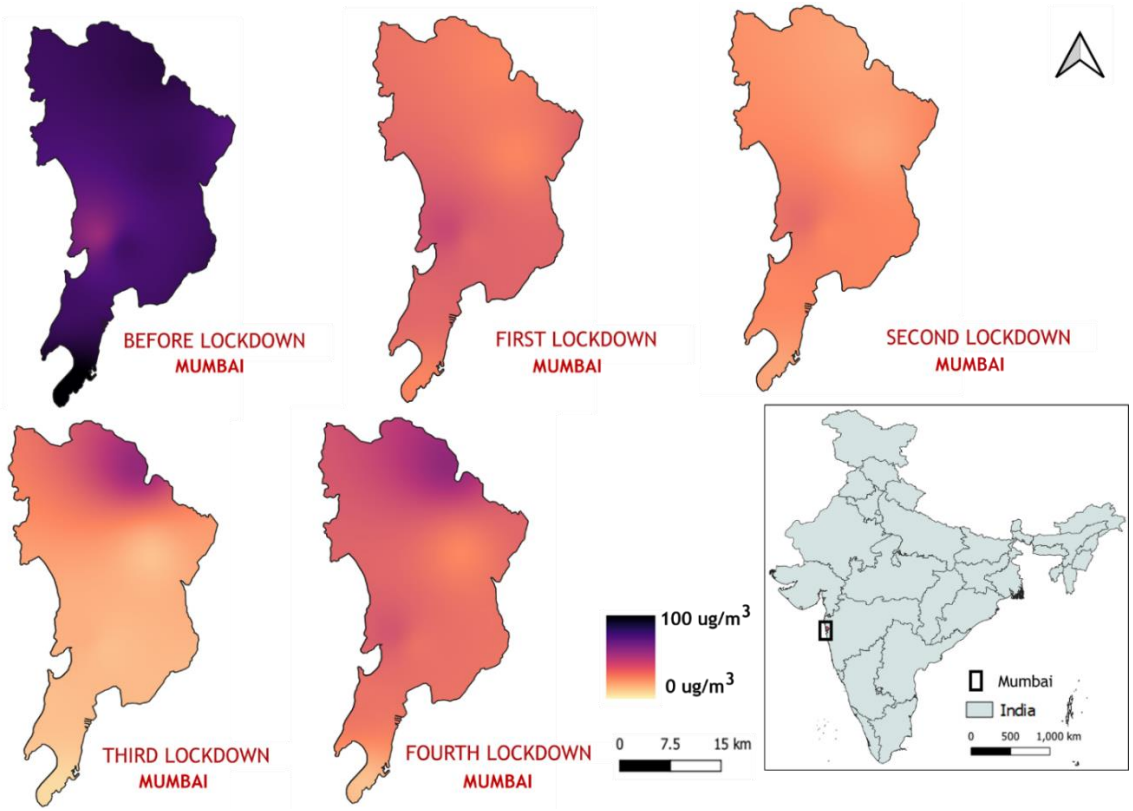


Figure 17: Variation of PM2.5 during various stages of lockdown for Mumbai.

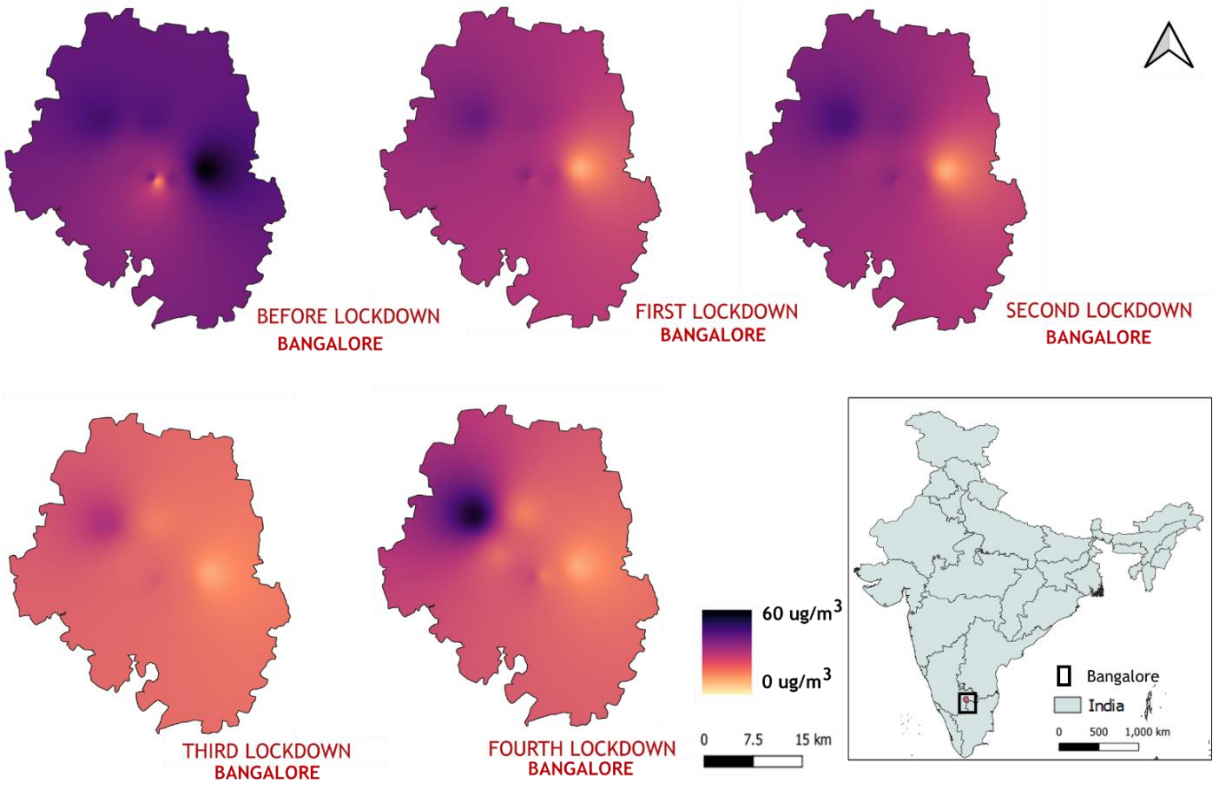


Figure 18: Variation of PM2.5 during various stages of lockdown for Bangalore.

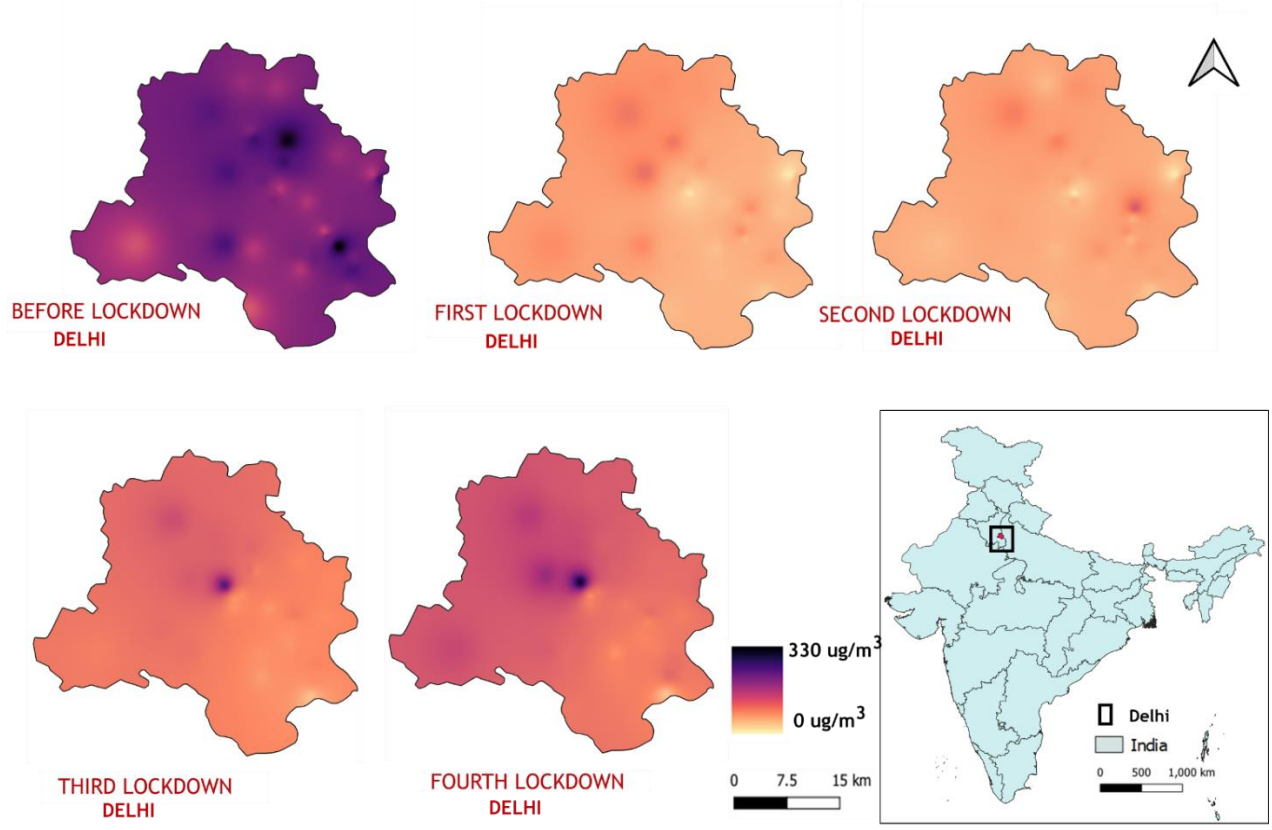


Figure 19: Variation of PM2.5 during various stages of lockdown for Delhi

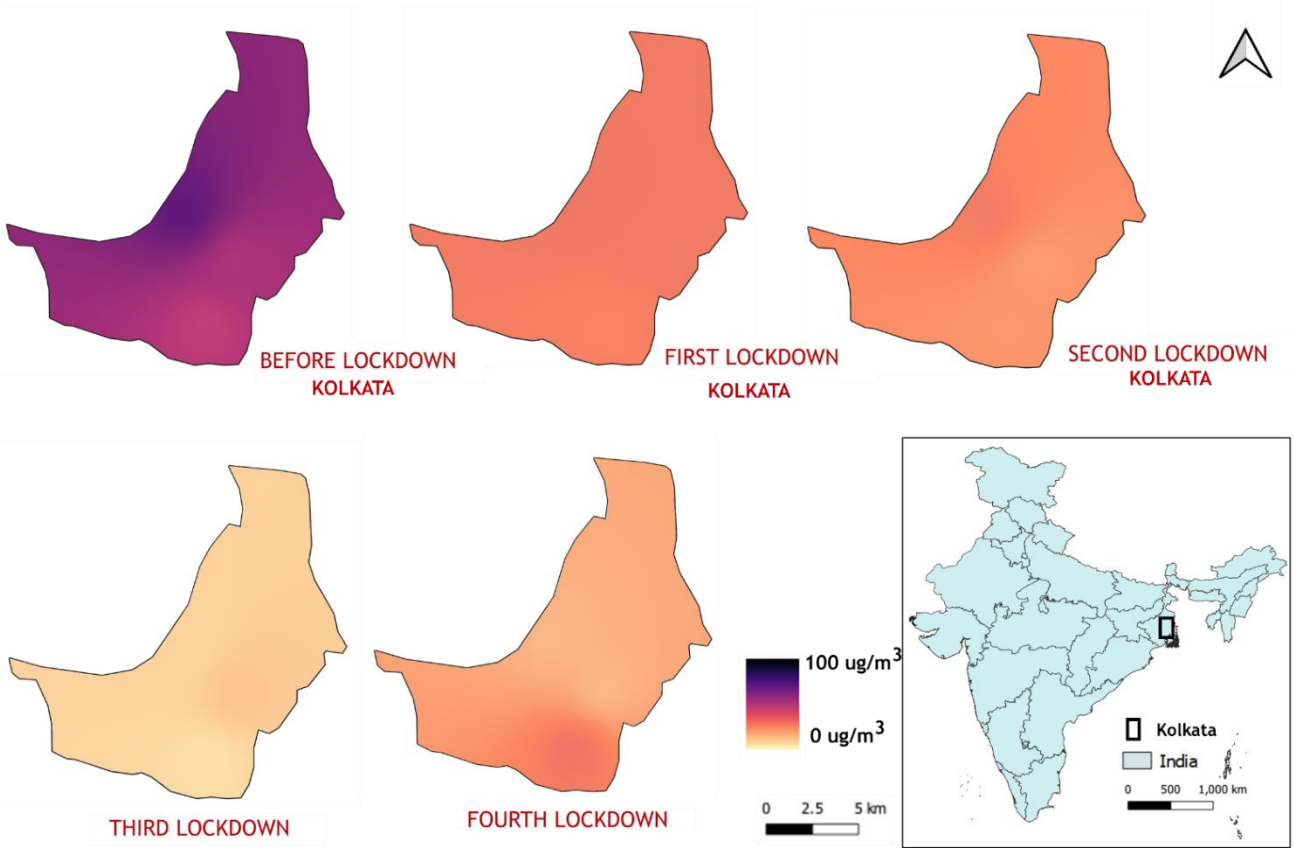
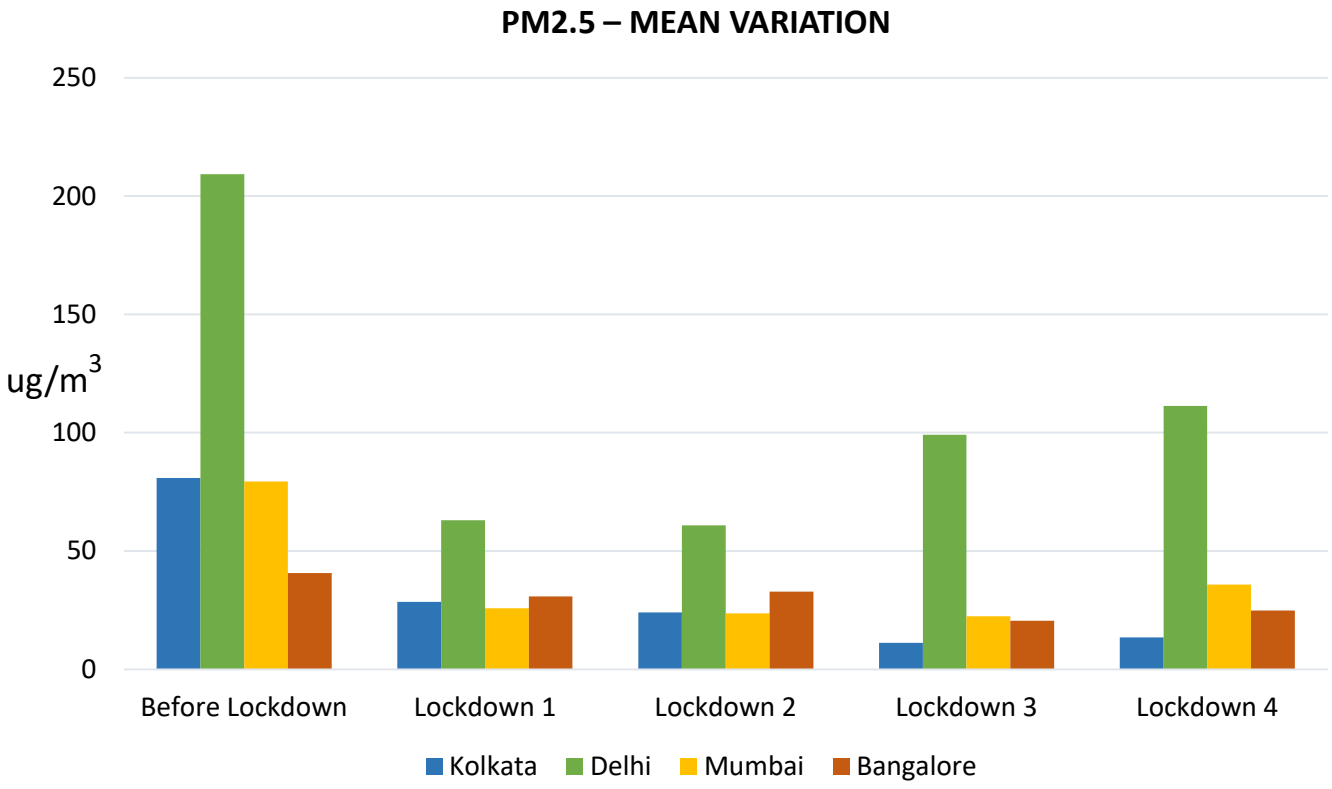


Figure 20: Variation of PM2.5 during various stages of lockdown for Kolkata.



12.1.4. **Inferences:**

- Before the lockdown, the value of PM2.5 was recorded highest for Delhi, while Bangalore had the lowest value.
- Till the 2nd lockdown, the values for PM2.5 for all cities have drastically decreased.
- After the 2nd lockdown, the value in Mumbai, Delhi and Bangalore have increased at a slower pace compared to Delhi.
- At the end of 4th lockdown, Delhi still has the highest value while Kolkata has the lowest values.
- From the maps, we can compare the highest values for each cities i.e**. Delhi – 330 ug/m^3 Mumbai – 100 ug/m^3, Bangalore – 60 ug/m^3 and Kolkata – 100 ug/m^3 .**
- From the graph, we can compare the percentage change in PM2.5 values, which is as follows:

  Change in PM2.5 (Before lockdown to 4th lockdown): **-83.28%** in Kolkata, **-46.85%** in Delhi, **-54.93%** in Mumbai while **-38.86%** in Bangalore.

12.2. Particulate Matter 10 (PM10)

12.2.1. **Source:**

PM10 is particulate matter 10 micrometers or less in diameter. PM10 also includes dust from construction sites, landfills and agriculture, wildfires and brush/waste burning, industrial sources, wind-blown dust from open lands, pollen and fragments of bacteria. [20]

PM_{10}		
Sectors	Winters	Summers
Residential	9%	8%
Agri. Burning	4%	7%
Industry	27%	22%
Dust (soil, road, const.)	25%	42%
Transport	24%	15%
Others	10%	7%

Figure 21: Contributing sectors for PM10 for Delhi city [31]

12.2.2. Impact of PM10:

Particles in the PM10 size range are commonly present in air and may be drawn into the body with every breath. In the lungs particles can have a direct physical effect and/or be absorbed into the blood. The specific effect of particles depends on their composition, concentration and the presence of other pollutants such as acid forming gases. [18]

12.2.3. Maps and Graph:

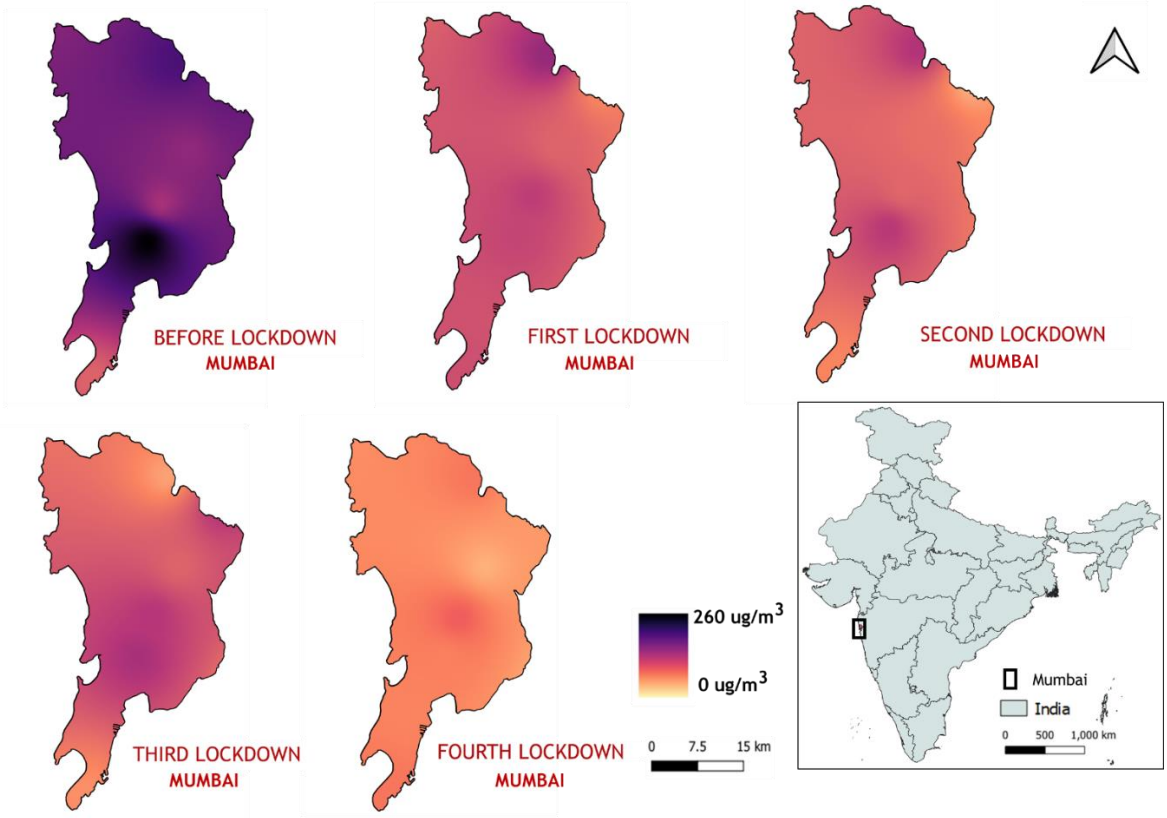


Figure 22: Variation of PM10 during various stages of lockdown for Mumbai.

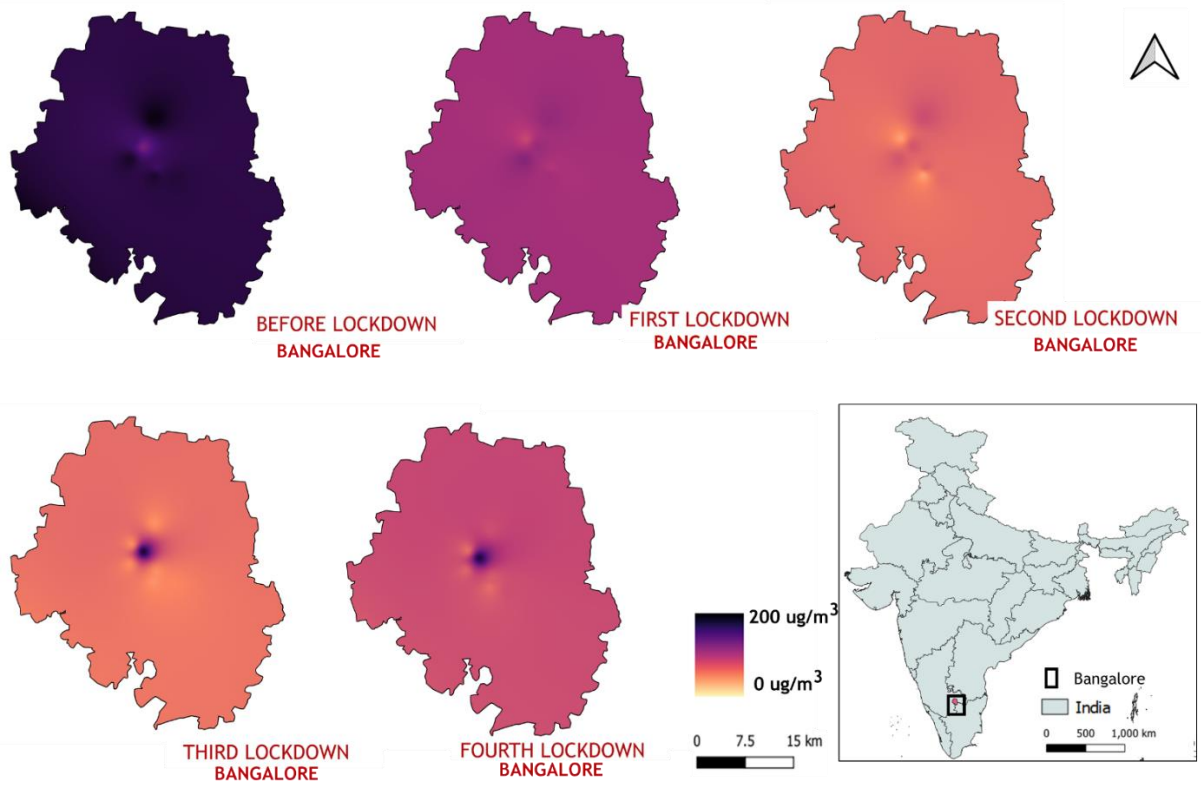


Figure 23: Variation of PM10 during various stages of lockdown for Bangalore.

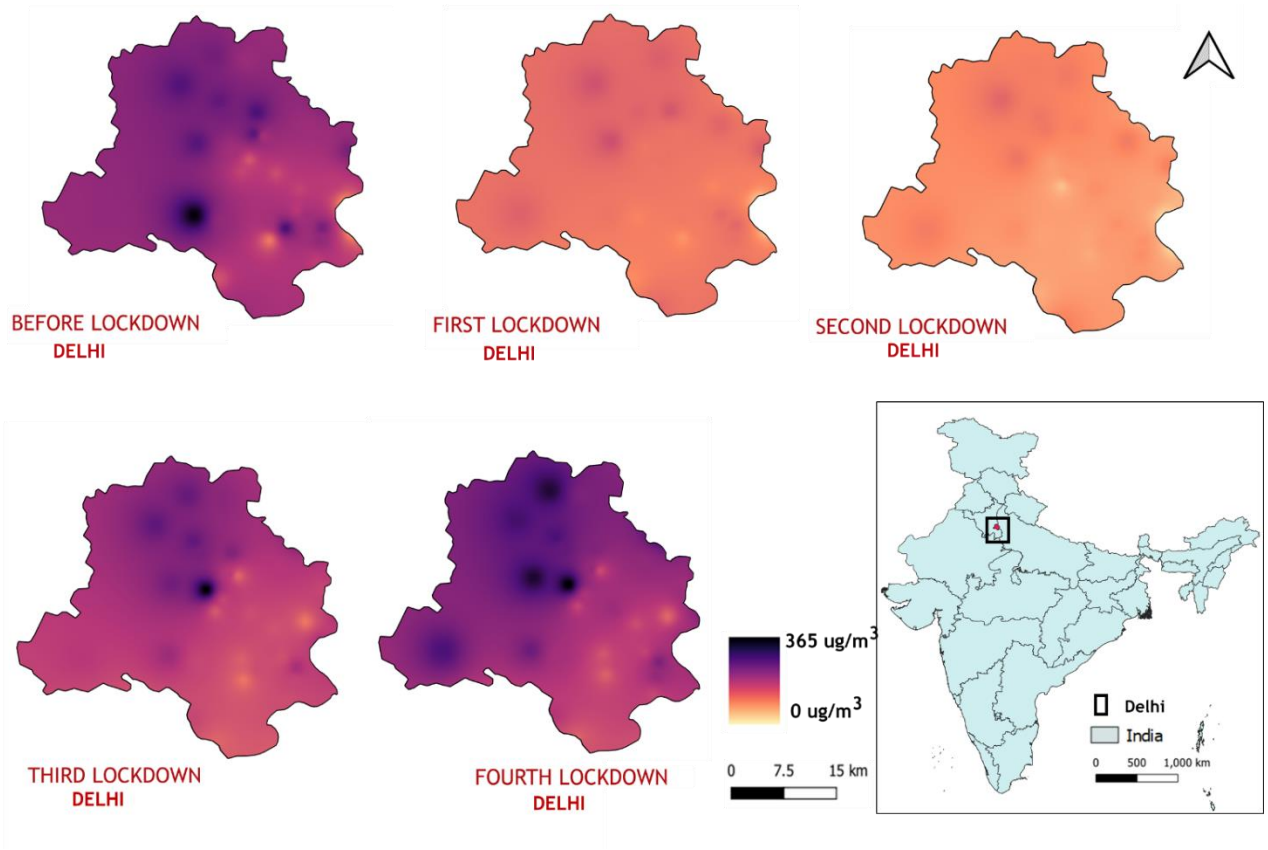


Figure 24: Variation of PM10 during various stages of lockdown for Delhi.

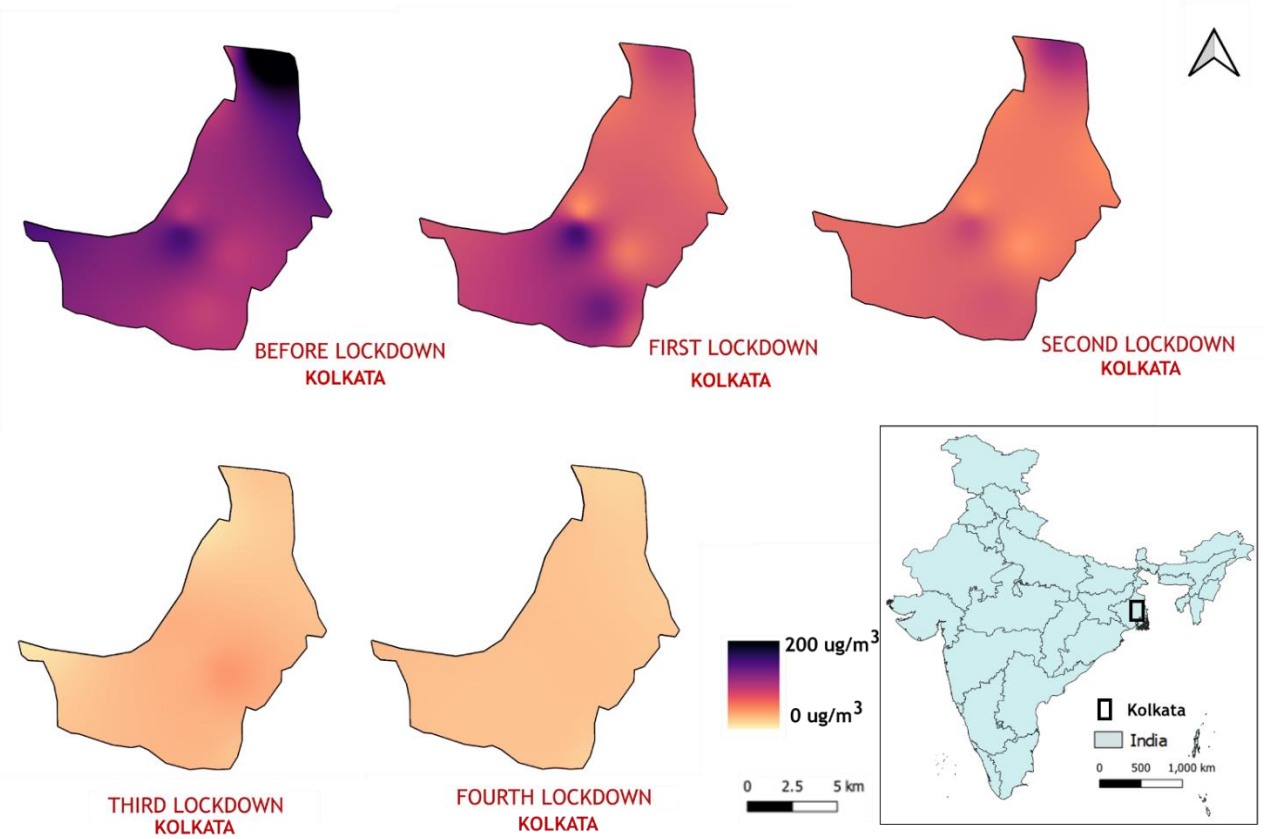
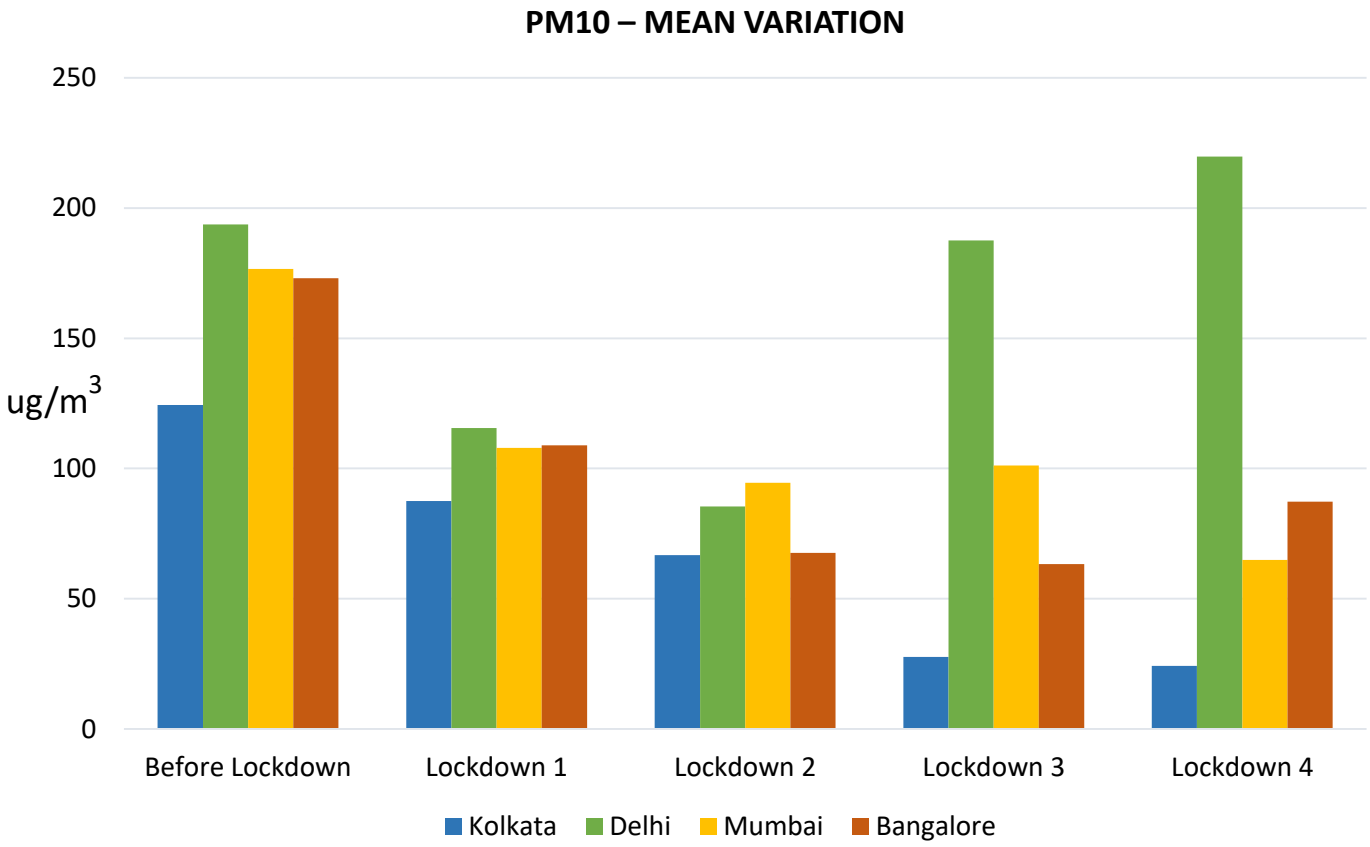


Figure 25: Variation of PM10 during various stages of lockdown for Kolkata.



12.2.4. Inferences

- Before the lockdown, the value of PM10 was recorded highest for Delhi, while Kolkata had the lowest value.
- Till the 2nd lockdown, the values for PM10 for all cities have drastically decreased.
- After the 2nd lockdown, the value in Mumbai and Delhi increased while in Kolkata and Bangalore it decreased at a slower pace.
- At the end of 4th lockdown, Delhi is still leading (even more than the before lockdown values) while Kolkata had the lowest values.
- From the maps, we can compare the highest values for each cities i.e. **Delhi – 365 ug/m^3, Mumbai – 260 ug/m^3, Bangalore – 200 ug/m^3 and Kolkata – 200 ug/m^3.**
- From the graph, we can compare the percentage change in PM10 values, which is as follows:

  Change in PM10 (Before lockdown to 4th lockdown): **-80.53%** in Kolkata, **13.42%** in Delhi, **-63.281%** in Mumbai, while **-49.58%** in Bangalore.

13. CURRENT SCENARIO

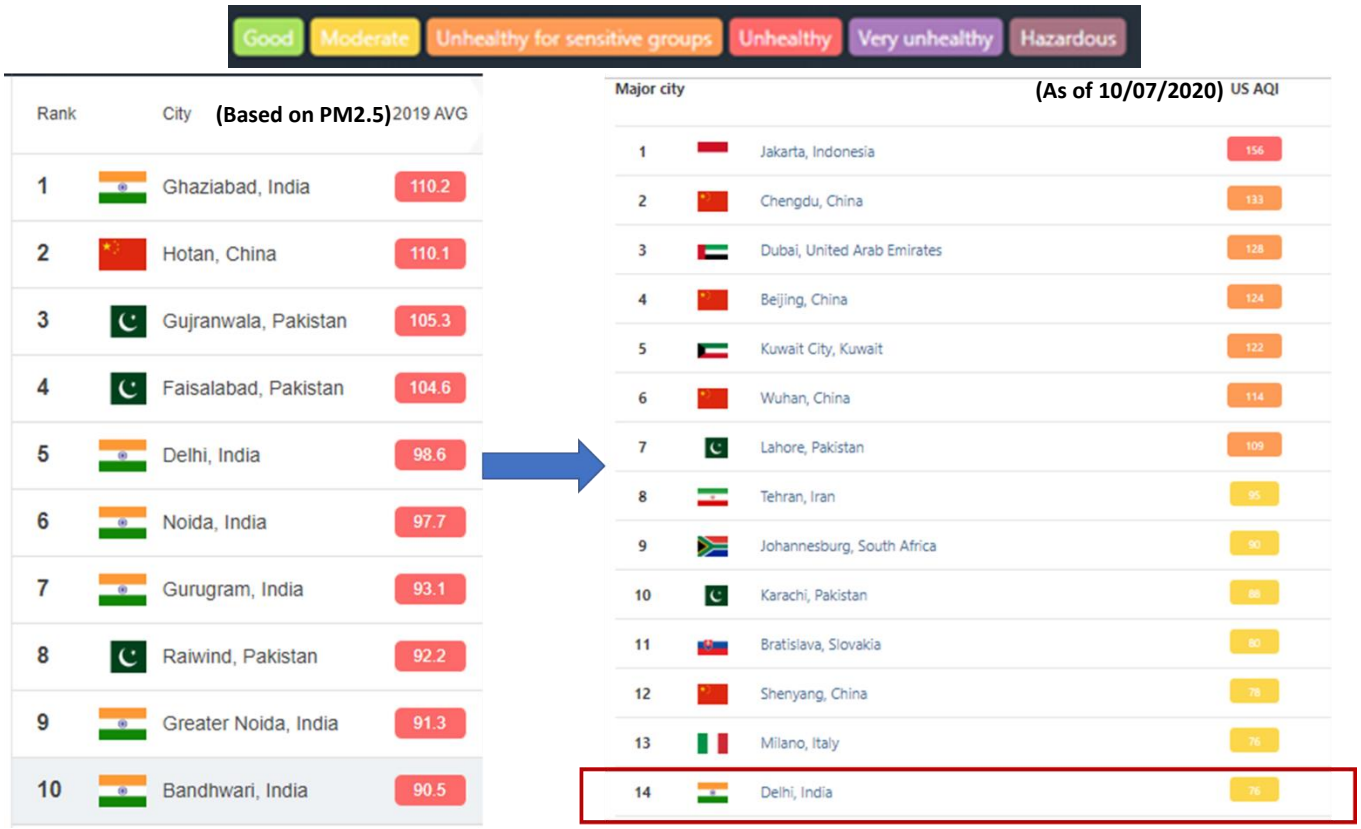


Figure 26: Comparison between the most polluted cities for year 2019 and year 2020. [32]

- Here, from the left side image, we can infer that in 2019, Ghaziabad was the most polluted city in the world based on PM2.5 concentration. Also from the list of top 10 most polluted cities in the world, six cities are from India. This is a very critical situation and should be taken seriously.
- While the image on the right-side shows the ranking after the lockdown (for the date of 10th of July, 2020). Here, we can see that now Delhi is at the 14th position in the list and the yellow colour indicates that the air quality has changed from hazardous to moderate.

Below shown image of India gate at Delhi is one of the classic examples of drastic improvement in air quality before and after the lockdown.

INDIA GATE

Figure 27: Before and after view of India Gate [33]

14. INFERENCES

The following are the overall inferences for SO2, NO2, CO, O3, PM10 and PM2.5, and the percentage of change for all the air pollutants is shown in the graphs below.

For SO2: -46.08% in hotspot1 and -50.14% in hotspot2.

HOTSPOT 1 : Villupuram, Cuddalore and Vridhachalam (Tamil Nadu)

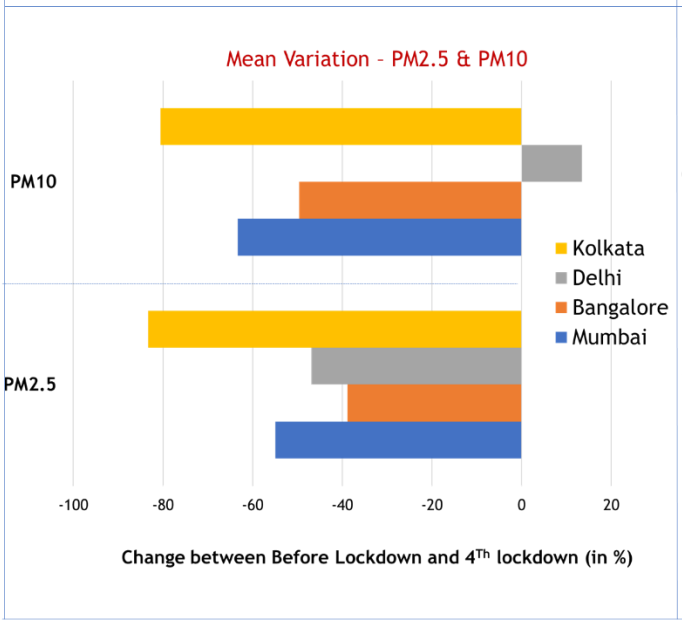
HOTSPOT 2 : Singrauli (M.P), Sonbhadra (U.P) and Surguja (Chhattisgarh)

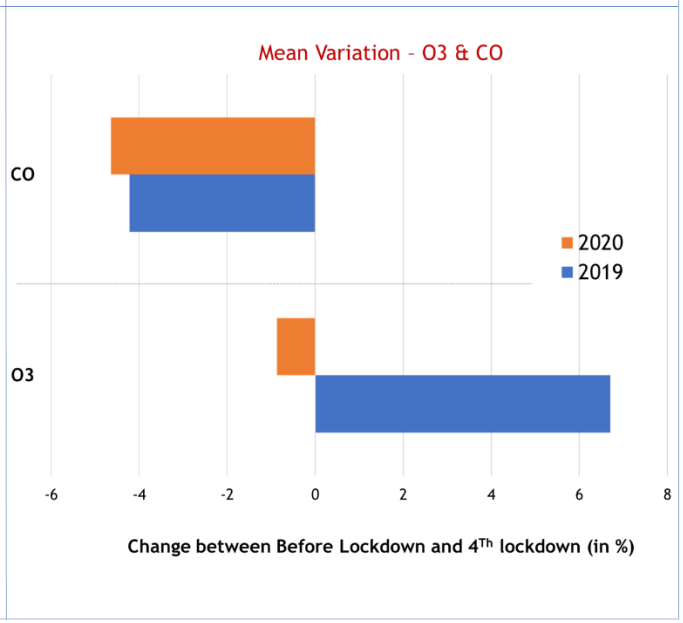
For NO2: -17.64% in hotspot1, 5.74% in hotspot2 and -22.77% in hotspot3.

HOTSPOT 1 : Delhi, Ghaziabad and Gautam Buddha Nagar (U.P), Faridabad (Haryana).

HOTSPOT 2 : Sidhi and Sonbhadra (M.P), Korba, Bilaspur, Raipur, Durg, Janjgir, Rajgarh, Jangir-Champu, Jharsuguda and Sambalpur (Chhatisgarh),

HOTSPOT 3 : Bankur, Bardhhaman and Birkhum (West Bengal), Jamtara, Dhanbad and Bokara (Jharkhand)





- For most of the air pollutants, the change in percentage was negative, which means the values at their hotspots or major cities for 4th lockdown, are decreasing compared to before lockdown values. This is a good sign and the authority should work to maintain the same with the help of environment-friendly alternatives.
- But there were exceptions also. For example, the change in PM10 at Delhi and in NO2 at Hotspot2 are positive, indicating that the value at the end of 4th lockdown was higher than the before lockdown values.
- For **Ozone**, the trend was supposed to be increasing (w.r.t. **2019 graph: 6.7%),** but due to lockdown the change is **-0.87% in 2020.**
- For **CO**, the trend was decreasing (w.r.t. **2019 graph: -4.22%),** and due to lockdown the change, observed in 2020 is -4.64%.
- For **PM2.5**, **Kolkata is showing maximum drop (-83.28%)** while **Bangalore is showing the least drop in change (-38.86%).**
- For **PM10**, again **Kolkata is showing the maximum drop (-80.53%)** while **Delhi on the other hand is showing an increment of 13.42%.**
- For **NO2**, a decrement is seen at **hotspot 1(-17.64%) and hotspot 3 (-22.77%),** while an increment of **5.74% is observed at hotspot2.**
- For **SO2**, a decrement is seen at both hotspots- **Hotspot 1(-46.08%) and Hotspot 2 (-50.14%).**

Hence, lockdown has helped in improving the overall air quality and therefore make a healthy environment for humans as well as flora-fauna to live in, and now it is our job to maintain the same. As we cannot stop the growth of industrialization and urbanization, we should definitely try to use more environment friendly and pollution-free alternatives.

15. SPOKEN TUTORIAL

15.1. What are spoken tutorials?

The Spoken Tutorial project is the initiative of the "Talk to a Teacher" project of the National Mission on Education through Information and Communication Technology, launched by MHRD, Govt of India.

Spoken Tutorial is a multi-award winning educational content portal. Here one can learn various Free and Open Source Software all by oneself. Our self-paced, multi-lingual courses ensure that anybody with a computer and a desire for learning can learn from any place, at any time and in a language of their choice.

Our engaging digital content ensures that learning happens at all levels - Basic, Intermediate and Advanced. Many of the software taught, are used in various disciplines of Engineering, pure Sciences and several other Under-Grad and Post-Grad studies. [21]

The link for the spoken tutorial is http://spoken-tutorial.org .

Figure 28: Courses offered by Spoken Tutorials [34]

15.2. Contribution for the Spoken Tutorial Project

The following are the scripts as a part of the Spoken Tutorial Project, to help the learners to understand the visualization tools like 'Heat Maps' and "Voronoi Polygons' and how to use Zonal statistics such as mean, maximum, minimum, count etc. for vector zones using batch processing method in QGIS.

15.2.1. Use of Zonal Statistics Tool by batch processing method.

- What does Zonal Statistics Tool do?
- Advantages of Batch processing.
- How to use zonal statistics tool with batch processing?
- Interpretation of the results.

15.2.2. Heat Maps and Voronoi Polygons

- What are 'Voronoi Polygons' and 'Heat Maps'?
- Applications of "Voronoi Polygons' and 'HeatMaps'.
- How to create them using QGIS.
- How to interpret the outputs.

16. REFERENCES

1. “GIS (Geographic Information System)”, National Geographic.
   Available at: https://www.nationalgeographic.org/encyclopedia/geographic-information-system-gis/
2. “QGIS - The Leading Open Source Desktop GIS”, Discover QGIS.
   Available at: https://www.qgis.org/en/site/about/index.html
3. Paolo Cavallini (August 2007). "Free GIS desktop and analyses: QuantumGIS, the easy way", The Global Geospatial Magazine.
   Available at: https://www.geospatialworld.net/
4. David J Cennimo (July 2020), What is COVID-19?, Medscape.
   Available at: https://www.medscape.com/answers/2500114-197401/what-is-covid-19
5. Mukesh Rawat (March 2020). "Coronavirus in India: Tracking country's first 50 COVID-19 cases; what numbers tell", India Today
   Available at: https://www.indiatoday.in/india/story/coronavirus-in-india-tracking-country-s-first-50-covid-19-cases-what-numbers-tell-1654468-2020-03-12
6. Isabelle Gerretsen (April 2020), “How air pollution exacerbates Covid-19”, BBC
   Available at: https://www.bbc.com/future/article/20200427-how-air-pollution-exacerbates-covid-19
7. At Geneva (July 2020), “WHO acknowledges 'evidence emerging' of airborne spread of coronavirus”, The Hindu
   Available at: https://www.thehindu.com/news/international/who-acknowledges-evidence-emerging-of-airborne-spread-of-coronavirus/article32017028.ece
8. Jacob Koshy (February 2020), “India 5th Most Polluted Country In The World: Report”, The Hindu
   Available at: https://www.thehindu.com/news/national/21-indian-cities-among-worlds-30-most-polluted-delhi-worlds-most-polluted-capital-city-report/article30913690.ece#:~:text=India%20was%20the%205%20most,primarily%20works%20on%20air%20filtration.
9. Lockdown time intervals
   Available at : https://en.wikipedia.org/wiki/COVID-19_pandemic_lockdown_in_India
10. Shagun Kapil (August 2019), “India emits the most sulphur dioxide in the world:, DownToEarth
    Available at: https://www.downtoearth.org.in/news/air/india-emits-the-most-sulphur-dioxide-in-the-world-66230
11. “Nitrogen dioxide”, Ministry foe the Environment, New Zealand
    Available at: https://www.mfe.govt.nz/air/specific-air-pollutants/nitrogen-dioxide#:~:text=The%20main%20source%20of%20nitrogen,commercial%20manufacturing%2C%20and%20food%20manufacturing.

12. “Ground-level Ozone”, Environmental Protection agency, United States.
Available at: https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics#:~:text=Ozone%20can%20be%20%E2%80%9Cgood%E2%80%9D%20or,ultraviolet%20radiation%20from%20the%20sun.&text=Ozone%20occurs%20both%20in%20the%20Earth's%20upper%20atmosphere%20and%20at%20ground%20level.
13. “Good Up High Bad Nearby - What is Ozone?”, AirNow.
Available at :
https://cfpub.epa.gov/airnow/index.cfm?action=gooduphigh.index#:~:text=The%20troposphere%20generally%20extends%20to,harmful%20ultraviolet%20(UV)%20rays.
14. Amit Kumar Gorai , Paul B Tchounwou, Gargi Mitra (2017), “Spatial Variation of Ground Level Ozone Concentrations and its Health Impacts in an Urban Area in India”, PubMed
Available at: https://pubmed.ncbi.nlm.nih.gov/29033981/
15. Susanta Mahato, Swades Pal, Krishna Gopal Ghosh (April 2020), “Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India”, ResearchGate
Available at:
https://www.researchgate.net/publication/341040665_Effect_of_lockdown_amid_COVID-19_pandemic_on_air_quality_of_the_megacity_Delhi_India
16. Rajesh Kumar, Manish Naja, G. G. Pfister, M. C. Barth, G. P. Brasseur (January 2013), “Source attribution of carbon monoxide in India and surrounding regions during wintertime”, Advancing Earth and Space Science
Available at:
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/jgrd.50134#:~:text=It%20is%20found%20that%20the,and%20southern%20India%20(22%25).
17. Vibhor Sood , Shivani Sood, Pajesh Bansal, Umesh Sharma, Siby John (2014), “Traffic related CO pollution and occupational exposure in Chandigarh, India”, IJES
Available at: http://www.ipublishing.co.in/ijesarticles/fourteen/articles/volfive/EIJES51015.pdf
18. “Particulate matter (PM10 and PM2.5)”, Department of Agriculture, Water and the environment, Australian Government.
Available at: http://www.npi.gov.au/resource/particulate-matter-pm10-and-pm25#:~:text=Natural%20sources%20of%20PM10,storms%2C%20pollens%20and%20sea%20spray
19. “What is Particulate Matter 2.5 (PM2.5)?”, Eurpean Tech Serv NV.
Available at: https://etserv.be/glossary/particulate-matter-2-5-pm2-5/#:~:text=There%20are%20about%2025%2C000%20microns,the%20end%20of%20this%20sentence.
20. “Inhalable Particulate Matter and Health (PM2.5 and PM10)”, Air Resources Board, California.
Available at: https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health#:~:text=PM10%20also%20includes%20dust%20from,pollen%20and%20fragments%20of%20bacteria.

21. Mission, Spoken Tutorials, IIT Bombay.
    Available at: https://spoken-tutorial.org/mission/
22. The Hindu Net Desk (March 2020), “Coronavirus live updates | March 24, 2020”, The Hindu.
    Available at: https://www.thehindu.com/news/national/coronavirus-live-updates-march-24-2020/article31149240.ece
23. Deepika Pundir (June 2020), “Coronavirus Highlights: Centre Extends Lockdown Till June 30 With More Relaxations” , NDTV.
    Available at: https://www.ndtv.com/india-news/live-coronavirus-india-updates-over-7-900-covid-19-cases-in-india-in-last-24-hours-31-may-2020-2238035
24. “Fine Particles (PM 2.5) Questions and Answers”, Department of Health, New York State.
    Available at: https://www.health.ny.gov/environmental/indoors/air/pmq_a.htm
25. Arjun Sidam (December 2019), “Increased SO2 concentration in the air causes”, Toppr.
    Available at: https://www.toppr.com/ask/question/increasedso2concentration-in-the-air-causes/
26. Figure 1: https://gisgeography.com/what-gis-geographic-information-systems/
27. Figure 2: https://commons.wikimedia.org/wiki/File:Qgis-icon-3.0.png
28. Figure 3: https://www.iqair.com/us/world-most-polluted-countries
29. Figure 4: https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing
30. Figure 6:
    https://epaper.timesgroup.com/Olive/ODN/TimesOfIndia/shared/ShowArticle.aspx?doc=TOIDEL%2F2019%2F08%2F20&entity=Ar00401&sk=3B33B2BE&mode=text#
31. Figure 16 & Figure 21: https://www.teriin.org/sites/default/files/2018-08/AQM-SA_0.pdf
32. Figure 26: https://www.iqair.com/us/world-air-quality-ranking
33. Figure 27: https://edition.cnn.com/2020/03/31/asia/coronavirus-lockdown-impact-pollution-india-intl-hnk/index.html
34. Figure 28: https://spoken-tutorial.org/creation/view_brochure/