Temporal Analysis of Covid-19 and its Impact on Environment

Problem Statement

Covid-19 posed a global health crisis leading to complete shutdown (Mar 24- May 16, 2020). Noticeably, there was a sudden decline in peoples' movement around the city. Consequently one could hypothesize a reduction in emission vis-à-vis industry, transport and various other sources of pollution.

We investigate and quantify changes in pollutant and aerosol (NO2) levels across Bengaluru, India as a result of covid-19 lockdown and to perceive implications of reduced emissions on land surface and air. Further investigate if changes in atmospheric pollutants have impacted LST, Air Temperature. To do so, we would compare and contrast ground measurements and remotely sensed observations between March 2020 - May 2020 with those over the same months in 2019 and 2021

Overview

We quantitatively analyze and assess the impact of covid-19 on the environment by looking at air pollution as primary subject and its associated parameters.

Our approach is four-fold,

1. State our conjecture
2. Perform experiment to investigate #1

3. Perform statistical analysis of #2

4. Derive conclusion

1. Conjecture

Covid-19 had no effect on air quality in any year. There is no significant difference between mean in AQI over the years i.e., $H0 : \mu 1 = \mu 2 = \mu 3$; where μ_i represents population mean for year i.

We would like to challenge our hypothesis by analyzing air quality, concretely AQI and tropospheric NO2 over Bengaluru for the first 6 months of 2019-2021.

The lockdown period under all calculation considered here is from 24th March — 30th May 2020.

The selection of Bengaluru was due to the largest inflow of humans since 2000 and research confirms its unprecedented urban expansion in the last two decades.

2. Experiment

To begin, we visualize the air quality of Bengaluru by collecting data from ground sensors at Silk Board (Bengaluru $12.934209^\circ N, 77.590226^\circ E$) which has a profound traffic throughout the year. The mean AQI is calculated followed by comparison with various years. We then compare and contrast pre-covid months with covid months to dismiss anomalies.

Methods

The mean AQI is calculated for Bengaluru assuming a single point estimate spatially uniform. Since the data does not contain the Air Quality Index (measure of goodness of Air in qualitative terms), it was calculated as the maximum of sub-indices of other parameters as stated in the CPCB document. The code for AQI computation is here.

On visualizing the trend of Air Quality Index from ground station specifically during lockdown timeframe, we find a largely distinct separation of distributions for the year 2019 and 2020. Although not yet with certainty, it can be noticed that mean AQI for the year 2020 is lesser than that of 2019 and 2021. We would revisit this graph in the section 3 to ascertain our hypothesis.

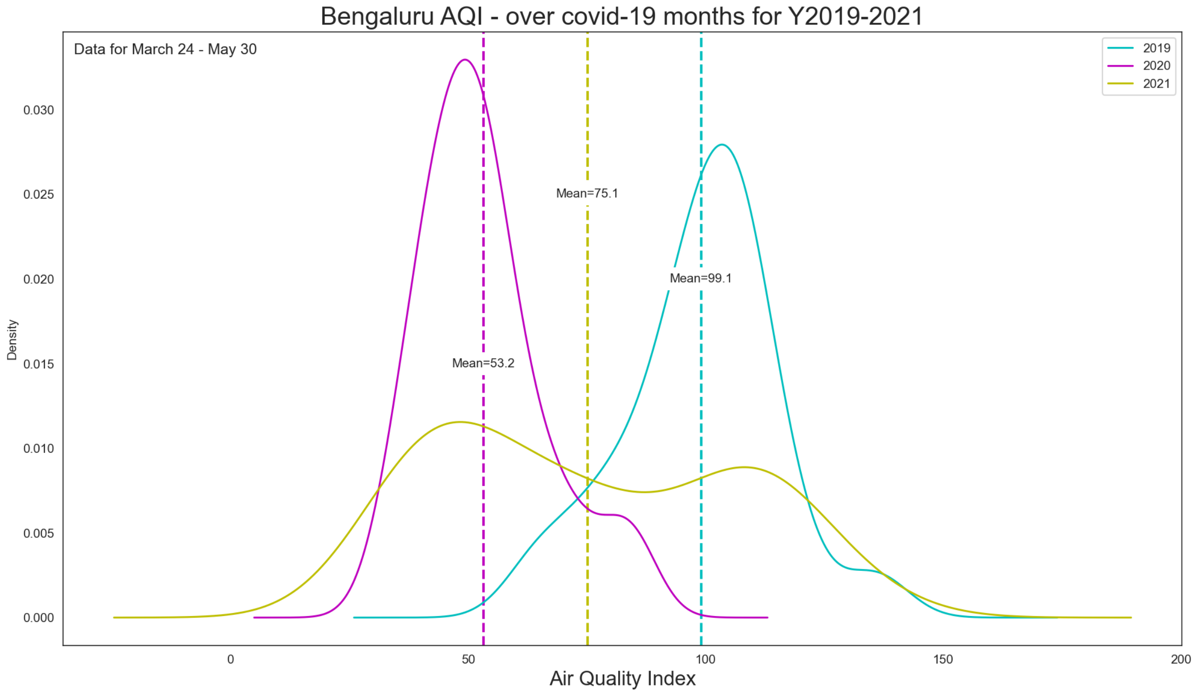

Figure 1: Comparison of Air Quality Index for Bengaluru from March 24 - May 30 over 2019-2021. A unimodal bell shaped curve with large separation of sample mean during 2019 and 2020 is observed. We analyze the data in section 3 to find reasons for such behavior.

Before drawing any conclusion from the above graph, it is important to consider potential phenomena that can influence AQI. While human-induced activities such as transport, industry, farming are known to influence, meteorological changes (precipitation, storm etc.) can also affect the final outcome. We could also think of this decrease as a policy/governance effect or rather an error in measurements. To negate these possibilities we look at AQI during pre-covid and post-covid months for every year.

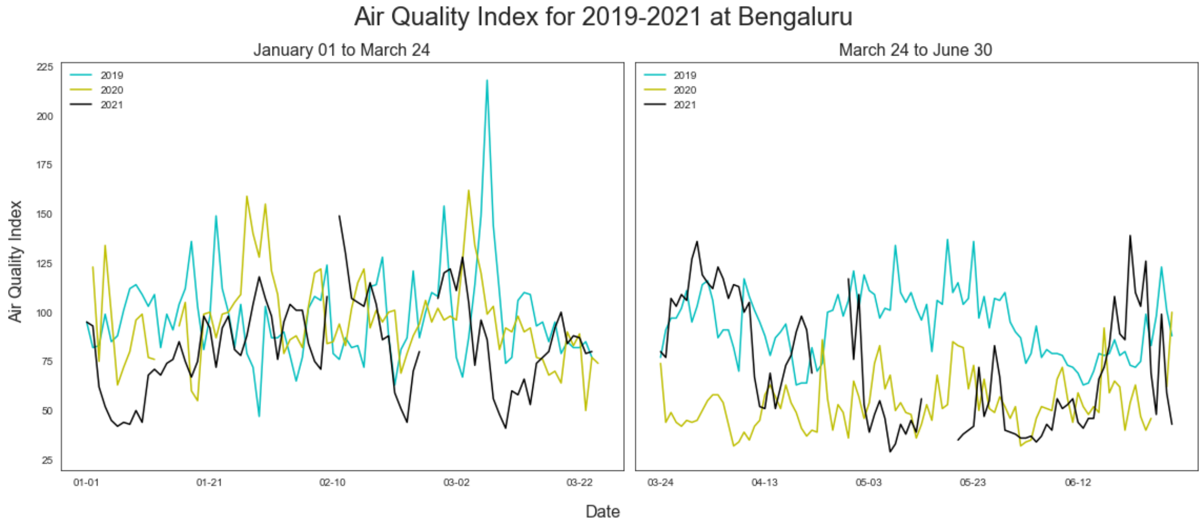

Figure 2: Air Quality Index pre and post covid month over the years. A rise in AQI is observed post-covid (yellow line) indicating unlocking of the city. Also, 2021 (black line) had a sharp rise after June 12 as another lockdown happened during April 5–15 June 2021 owing to rising cases in the city.

In Figure 2 we notice a rise in AQI at the start of June for 2020 and 2021. Similar to the extreme lockdown in 2020, the following year around the same time frame, there was a surge in cases owing to which a lockdown had to be put in place. This could be attributed to the drop in AQI in 2021 in the months of March and August. A similar pattern of variability is observed with remotely sensed tropospheric NO_2 as shown in Figure 3. A thorough statistical and quantitative analysis is performed in section 3

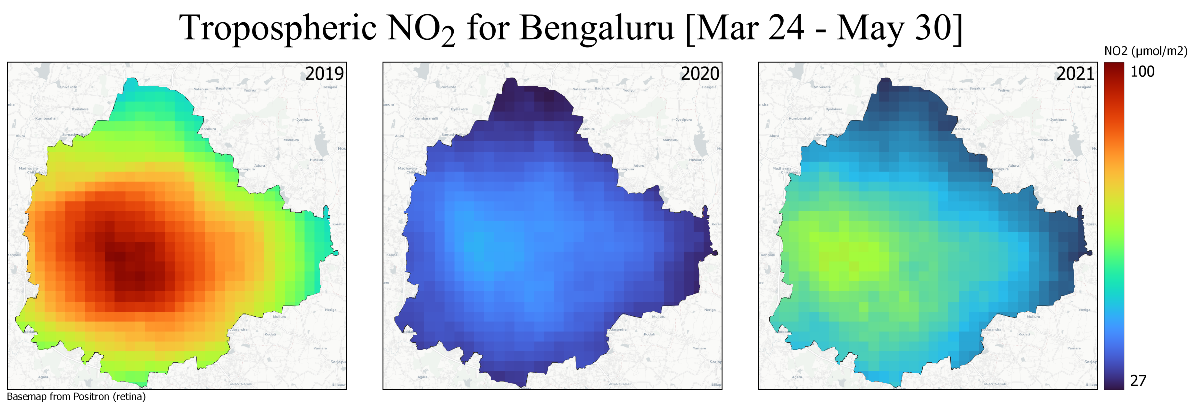

Figure 3: (resampled to 100m) Tropospheric NO_2 from **Sentinel 5P TROPOMI** sensor showing stark difference in measurements for the year 2020 as compared to 2019. The all blue signifies a uniform drop all over the city. 2021 also shows a significant dip compared to 2019 owing to lockdowns during that time frame as well. Mapped in QGIS.

3. Analysis

In this section we test our hypothesis by performing a one-way ANOVA statistical test for the year 2019-2021. If the test results (p-value) is less than the significance level, we reject the null hypothesis, and perform Tukey test to determine which population means are significantly different

While there are numerous parameters on which the quality of air depends on, only a handful of them are quantifiable. One of the parameters which we control for bias in our study is precipitation.

This is due to wet deposition, in which common air pollutants and pollen are washed away from the air into water streams, so aiding in air cleansing.

To decouple any variation induced by rainfall, we exclude our measurements when significant rainfall occurs over our region. To set up our experiment, we use CHIRPS daily rainfall dataset and set a threshold for exclusion. Any measurement on the day of rainfall or 1 day before, would not be included in our analysis. This is because air quality parameters are reported every day and average of previous 24 hour measurements are taken into account. This exclusion of rainfall would ensure we only include data which is unaffected by external factors.

Since there are several other parameters such as - anthropogenic activities, storms, fire and other non-quantifiable parameters which are not considered in this study, we assume a stricter significance level of 0.01 to ensure a robust outcome irrespective of large variance.

We perform a one-way ANOVA test to investigate if there is any significant difference in AQI due to covid-19. For this,

- Samples for every year from the ground station are taken. They can be assumed independent since values of AQI for previous year does not affect the current.
- Sample size is larger than 30 and thus normality condition is met.
- Variance is equal since the sample is collected from the same instrument.

The test revealed that there was a statistically significant difference in mean AQI between 2019, 2020 and 2021 $(F(2,134) = [47.592], p = 2.4191e-16)$. Thus, we reject the null hypothesis in favor of the alternative. This also means that at least two population means have different values.

To determine which population means are significantly different, we perform Tukey's HSD test which allows for pair-wise comparison.

Tukey's test found that the mean value of AQI was significantly different for every pair of years, but the difference in mean for 2019-2020 was far more than other pairs of years.

Treatment	p value	C.I. LB at 99%	C.I. UB at 99%

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2019 and 2020	0.000	54.216	28.767
2019 and 2021	0.001	-29.744	-2.990
2020 and 2021	0.000	12.009	38.247

Quantitatively, a drop of 41.937 ± 12.725 was observed in AQI for the year 2020 as compared to 2019.

Additionally, we use satellite data from Sentinel-5P's TROPOMI sensor to measure NO_2 for our analysis. NO_2 is generated primarily from air traffic and fossil fuel which would help us identify differences, if any, in air quality of the city.

The data is downloaded from Google Earth Engine as a time series with a single mean statistic over our Area of Interest (AOI) for the above said time period. We filter the measurements when there was significant precipitation over our AOI and perform statistical analysis.

We find that there was a statistically significant difference in mean tropospheric NO_2 between 2019, 2020 and 2021 with $(F(2, 135) = [87.752], p = 3.828e - 25)$. Thus, we reject the null hypothesis. Quantitatively, a drop of, $39.735 \pm 9.040\ \mu - mol/m^2$ was observed during 2019 and 2020.

On comparing satellite derived tropospheric NO_2 and ground-based measurements for the first 6 months of our study years, we find a moderate to high correlation between the parameters.

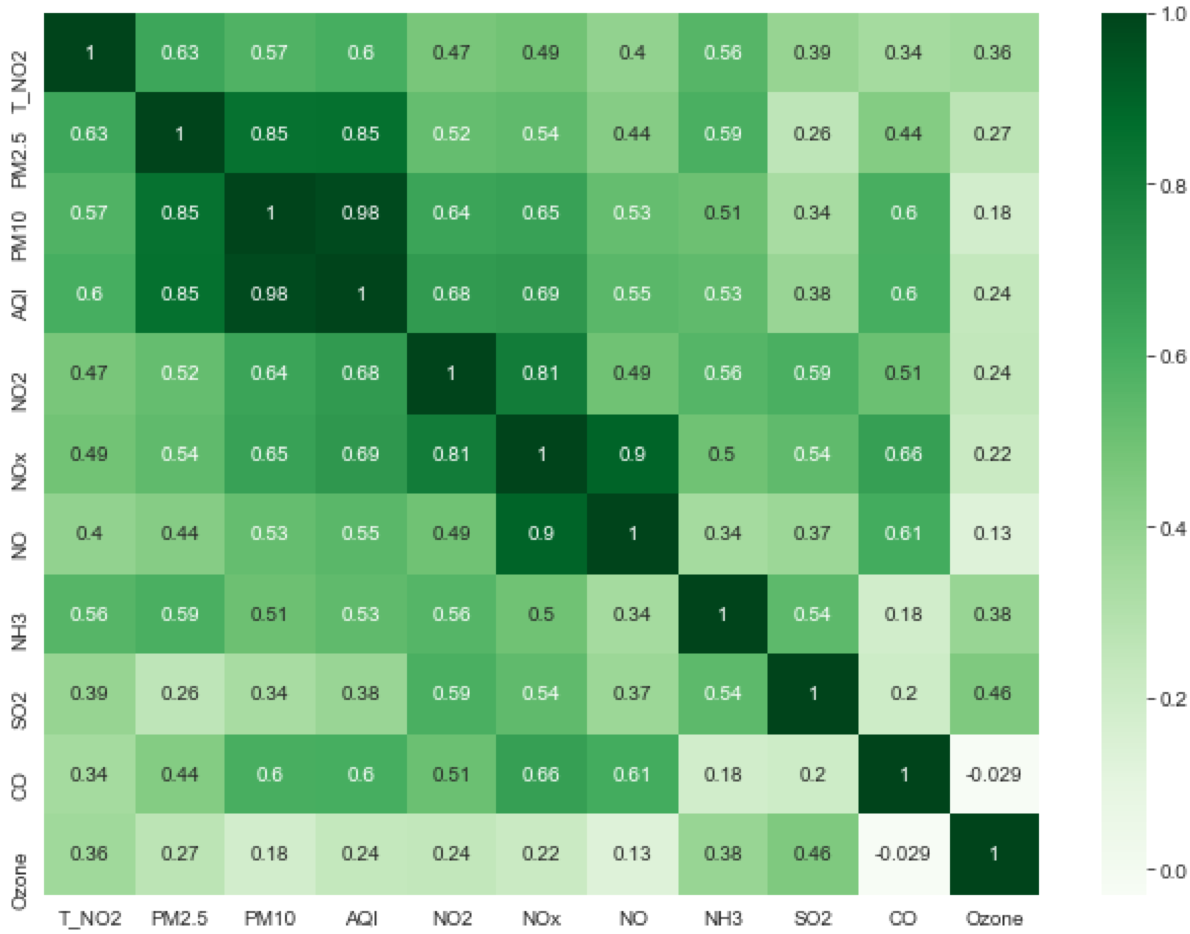

Figure 4: Moderately High correlation between satellite measurement (T_NO2) and ground station (AQI). We also see high correlation between various ground parameter and AQI since AQI is a function of ground measurements.

The find that remotely sensed measurements tally with the ground and it can potentially add value to provide AQI at a large spatial level by modeling air quality index as a function of satellite based measurements.

From the above analysis we can conclude that there was a decrease in AQI. We now investigate if changes in atmospheric pollutants have impacted Land Surface Temperature (LST) and Air Temperature (AT). To do so, we would look at two remotely sensed products namely, MOD11A1 and ERA-5 reanalysis measurements between March 2020 - May 2020 with those over the same months in 2019 and 2021 respectively to quantify our assumption.

Various studies have modeled LST for the impact of heat exchange in changing urban environments. With increase in AT due to increase in atmospheric pollution, LST is assumed to increase as more heat is retained by earth for a long period of time.

The initial thought was to use Landsat-8 data to detect changes in LST but due to its temporal resolution, we had to compromise with MODIS for statistical analysis. But here we demonstrate the changes in LST over the timeframe using single a scene representative of the entire timestamp (**Figure 5**).

We visualize Landsat Collection 2 Level 2 Science Product which contains surface temperature measurements with spatial resolution 30m and temporal frequency 16 days.

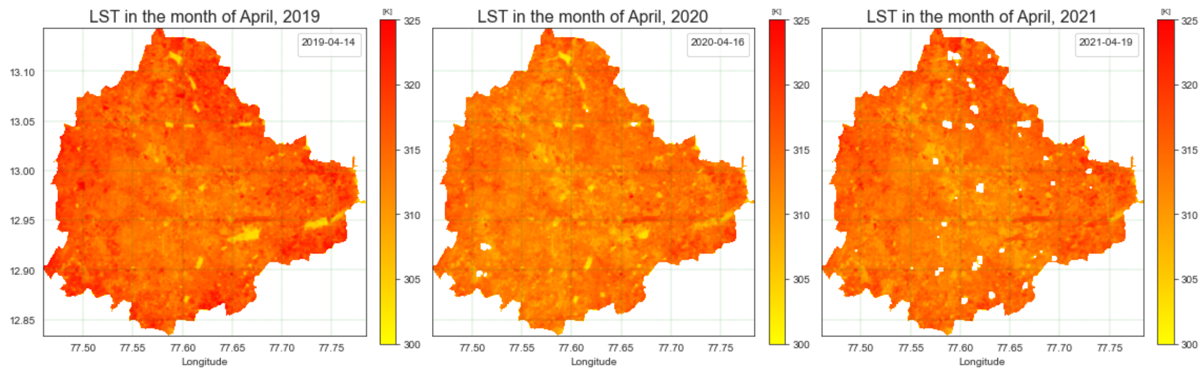

Figure 5: Comparison of LST over Bengaluru in the month of April. It was during this period that lockdown was ongoing. Data has been filtered for any effect from rainfall. The white artifacts are masked pixels due to clouds.

At first glance it looks like Land temperature in April for 2020 was cooler than other years. But we would need to quantify before jumping to conclusions. So we now visualize LST and AT for the first 6 months of every year (**Figure 6**).

The time of acquisition for MOD11A1 is variable but around 0010 to 0011 hours LMT, which is about 5:30 Hours ahead from UTC time. Similarly for AT, we acquire our data around 5:00 UTC which translates to 00100 - 0011 hours IST.

Data for Time Series LST is available from MOD11A1 satellite with temporal frequency of $1\ day$ and spatial resolution of $1km$ while AT data is downloaded from ERA-5 reanalysis with temporal frequency of $1\ hour$ and spatial resolution of 0.25°

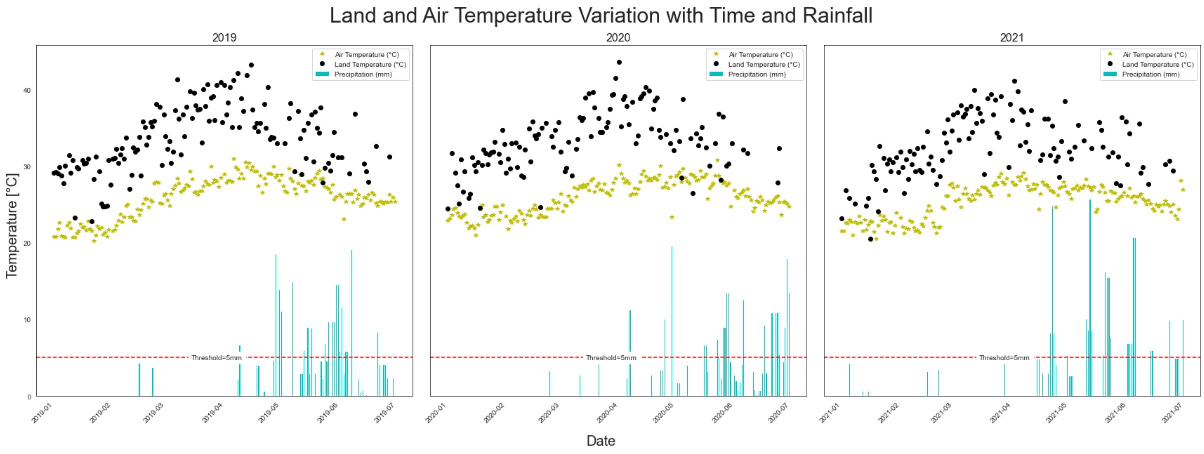

Figure 6: A plot showcasing difference in air and surface temperature over the first 6 months over 2019-2021. The bar plot is rainfall (mm) on that day. We notice a drop in air and land temperature when heavy rainfall occurs.

We see that AT is lower than LST which confirms to previous studies on their relationship.

Additionally, looking at AT time series before and during lockdown, we find no significant difference. We can notice a sudden drop in air temperature which can be attributed to precipitation or error in measurement. But on performing ANOVA test on AT we find contrasting results. The test revealed a statistically significant difference in mean AT $(F(2, 139) = [26.157], p = 2.281454e - 10)$. On performing Tukey's HSD test, it was found that there was a difference in mean AT between years 2019 and 2021; 2020 and 2021.

Treatment	p value	C.I. LB at 99%	C.I. UB at 99%
2019 and 2020	0.136	-1.053	0.224
2019 and 2021	0.000	-2.1506	-0.866
2020 and 2021	0.000	-1.722	-0.465

Quantitatively, a decrease of $1.510 \pm 0.642 \ ^\circ C$ was observed for 2021 as compared to 2019 and a decrease of $1.094 \pm 0.628 \ ^\circ C$ for the year 2020 and 2021.

In contrast, LST, though the difference in mean was statistically significant, on performing Tukey's HSD test, it was found that there was a difference in mean LST between years 2019 and 2021 only.

With LST, it was observed that there was a drop of $2.599 \pm 2.455^\circ C$ for the year 2019 and 2021.

This anomalous behavior can be attributed due to the capacity of earth to hold the heat over the years. Air quality improvement does not necessarily translate linearly to surface temperature. A decrease in concentration of pollutants could modify land temperature in both positive and negative ways as a result of changes in solar radiation, absorption and scattering.

Over the years, Intergovernmental Panel on Climate Change (IPCC) has confirmed a rapid increase in temperature of the earth due to rise in greenhouse gasses, and it may take a significant amount of effort to revert the anomaly. Since the conductive capacity of earth (solid) is higher than air (gas), it may lead to latency in response to changes in atmospheric anomaly.

Moreover, it is reported that, the anomalous increase which was supposed to happen for 2021 in global temperature, was nullified as a result of pandemic and excess rainfall that followed in 2020.

To state that decrease in air quality affects AT would not be wrong but to assert the statement with confidence would require additional research including correction for bias in AT which result from meteorological effect and natural variability.

Further work is needed to understand and attribute the cause of decrease in atmospheric temperature through application of net radiation on earth.

4. Conclusion

Satellite remote sensing is certainly a valuable tool for mapping and assessing air pollution due to its synoptic view and systemic delivery.

Our analysis on effect of covid-19 on environment revealed the following

- Air Quality Index was used as the primary indicator to ascertain the impact of lockdown on environment.
- There was a drop in AQI for Bengaluru of about 43.791 ± 7.86 for the year 2020 as compared to 2019.
- Land Surface Temperature did not have any effect as a result of improved air quality but Air Temperature showed a significant increase for the year 2019 and 2021; 2020 and 2021.
- In case of LST, a single point statistic cannot be representative of entire region due to variable
- Near identical condition are necessary to ascertain the difference in various atmospheric parameter are not a coincidence but in fact because of decline in anthropogenic activity during lockdown. To ascertain this, we undertake measures to control for precipitation.

Key outcomes or takeaways from your solutions.

- The outcome from our analysis is that air quality improved as a result of the lockdown. Moreover the effect seems to have lasted for another year.
- Year 2021 was cooler than 2020 and 2019.
- Moderate to strong correlation between remote sensing and ground measurements.

Involvement of geospatial data

The solution heavily relied on geospatial data. Rainfall, Atmospheric parameter, Land and Air Temperature measurements were taken from various satellites. Data Collection from CPCB, CHIRPS, Terra MOD11A1, Sentinel-5P, Landsat 8, ECMWF ERA5.

- CPCB — Daily Air Quality data for Silk Board Station
- CHIRPS - Daily Rainfall data at $5566\ m$ resolution
- Sentinel-5P TROPOMI NO_2 — Daily Tropospheric vertical column NO_2 data at $7 \times 3.5\ km$ resolution
- MODIS LST product MOD11A1 — Daily Land Surface Temperature at $1\ km$ resolution
- Landsat 8 Collection 2 Level 2 — 16-day Land Surface Temperature at $30\ m$ resolution
- ERA-5 Single Level 2-m Temperature - Hourly $2\ m$ Air Temperature at 0.25° resolution

Further modification in terms of data and methodology

In terms of data,

- Use of Air temperature measurement (from IMD AWS) to quantify the relationship with satellite based measurements.
- Sixteen day temporal visit and also 1000 m spatial resolution from MODIS are not adequate to accurately analysis variability in LST. Improvement in LST by combining MODIS, Landsat and ERA-5 product to increase temporal and spatial resolution.
- Look at traffic condition (number of accidents reported, number of vehicle purchases) or noise pollution levels as a result of drop in air quality. Verify if cause of air/noise pollution is traffic or industry with MODIS AOD product.

In terms of methodology,

- Control for other meteorological parameters: fires, storm.

- Compare and contrast for a large time-scale.
- Perform spatial-temporal analysis i.e., include more geographical location to measure the difference in results.
- Model ground-measurements (AQI) with satellite data to provide insights at higher spatial and temporal resolution.