A REPORT

ON

AIR POLLUTION CORRELATION WITH URBANISATION

BY

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# Abstract

Air pollution related studies have become a vital part of climate science due to pollutions impact on the environment and on human well-being. The effect of air pollution on human health has been well documented and researched. Various pollutants like Nitrogen Dioxide (NO2), Carbon Monoxide (CO), Carbon Dioxide (CO2), Sulphur dioxide (SO2) etc. when inhaled can cause severe damage to the lungs and other organs over time. They can also cause breathing issues like asthma and contribute to allergies.

On a larger scale these pollutants also contribute to global warming and phenomena such as acid rain. As climate change is becoming a larger and larger issue, tracking what factors contribute to air pollution has become more and more vital. One of the largest factors contributing to climate change is human activity. As our population has increased and our cities have rapidly developed, our use of fossil fuels for energy has also skyrocketed. For this project, the region of interest is Hyderabad, a growing metropolitan city in India. As it has grown and expanded over the previous few decades, air pollution has become a significant issue, caused by several factors including increasing population density, industrial activity, and vehicular traffic.

This project aims to prove a direct correlation between air pollution and urbanisation. The region of study is Hyderabad, a growing metropolitan city in India. The region includes urban, peri-urban and rural areas. The study uses data from Sentinel 5-P satellite’s TROPOMI sensors for air quality. For data on urbanisation data Normalized Difference Vegetation Index (NDVI) and Nighttime Land Surface Temperature (NLST) data from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor were used as well as nighttime lights (NTL) data obtained from the Visible Infrared Imaging Radiometer Suite (VIIRS). Using these datasets, it is possible to show a direct correlation between air pollution and increasing urbanisation.

# Literature Survey

Remote sensing and machine learning using air pollution data has become quite widespread. Many studies have been done using machine learning models to predict future levels of pollutants using different methods. These include classical methods such as Kth Nearest Neighbours (KNN) and Support Vector Regression1 , as well as deep learning methods such as Artificial Neural Networks2 . More recently models such as LSTMs3 as well as combinations of CNNs and LSTMs have also been put forward4. Graph Neural Networks have also been used to model the spatial component of such datasets with more accuracy5,6.

Studies have also been done on the relationships between air pollution and increasing urbanisation in growing cities7.

With the introduction of Sentinel 5-P’s TROPOMI sensor, high resolution global air pollution data has become easily accessible. A variety of different studies have used this data. Some examples include analysing data to assess vulnerability in certain areas8, conducting statistical analysis to identify the effect of anomalies such as lockdowns during the COVID-19 pandemic9, temporal zoning of air pollution for health management10, and exploring relationships between air pollutants and geographical and demographic data11. Some studies also combine Sentinel data with newer machine learning techniques such as transformers to predict future air pollution levels12.

Work has also been done on combining data from ground stations with satellite data to make more accurate predictions13. This includes various interpolation methods such as kriging interpolation. Similar studies have analysed pollution spatiotemporally using methods such as Morans -114and Local Indicators of Spatial Association (LISA)15 which are special methods used to identify spatial autocorrelation.

This project exploring the relationship between air pollution and urbanisation in Hyderabad builds upon previous worse segregating urban, peri-urban and rural areas16. It uses some of the same indicators such as NDVI, NLST and NTL to differentiate between rural and urban areas and uses different correlation metrics to establish a relationship between air pollution and urbanisation.

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# Datasets

This study used a variety of different data sets for air pollution data and for indicators of urbanisation.

Sentinel 5-P datasets:

Data from Sentinel 5-P’s TROPOMI sensor was used for air quality. Data for a variety of different pollutants was collected:

* Nitrogen Dioxide (NO2)
* Formaldehyde (HCHO)
* Carbon Monoxide (CO)
* Ozone (O3)
* Sulphur Dioxide (SO2)

Sentinel 5-P data is available from April-2018 to the present. The maximum resolution available is “5.5 x 3.5" km, a spatial resolution of 5.5 km in the satellite flight direction and 3.5 km in the perpendicular direction at nadir. Data released before 6 August 2019 had a resolution in the flight direction up to 7 km. To maintain uniformity, the lower resolution was used. All the data was in the form of L-2 products. It was obtained through the Sentinel Hub API.

Normalized Difference Vegetation Index (NDVI):

The Normalized Difference Vegetation Index (NDVI) is a widely used remote sensing index that measures the density and health of vegetation. It is calculated using the difference between near-infrared (which vegetation strongly reflects) and visible red light (which vegetation absorbs) from satellite imagery. NDVI values range from -1 to +1, where higher values indicate healthy, dense vegetation, while lower values signify sparse or stressed plant cover, barren land, or water bodies.

This data was collected from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. The available resolution was 250m. It was obtained through the Google Earth Engine API.

Nighttime Land Surface Temperature (NLST):

The Nighttime Land Surface Temperature (NLST) is a metric used to estimate the temperature of the Earth's surface using satellite data. By standardizing land surface temperature measurements, NLST helps assess thermal conditions across different regions and time periods. It plays a key role in understanding the effects of urbanization, climate change, and land use on surface temperatures. NLST is commonly used in studies related to the urban heat island effect, environmental monitoring, and the interaction between land cover and atmospheric processes.

This data was collected from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor.

The available resolution was 1000m. It was obtained through the Google Earth Engine API.

Nighttime Light (NTL):

Nighttime Lights (NTL) data refers to satellite observations of artificial lighting on the Earth's surface during nighttime. This data is used to monitor human activities, such as urbanization, economic development, and infrastructure growth. NTL captures the intensity and distribution of lights, making it valuable for studying the expansion of cities and tracking population density.

This data was taken from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor.

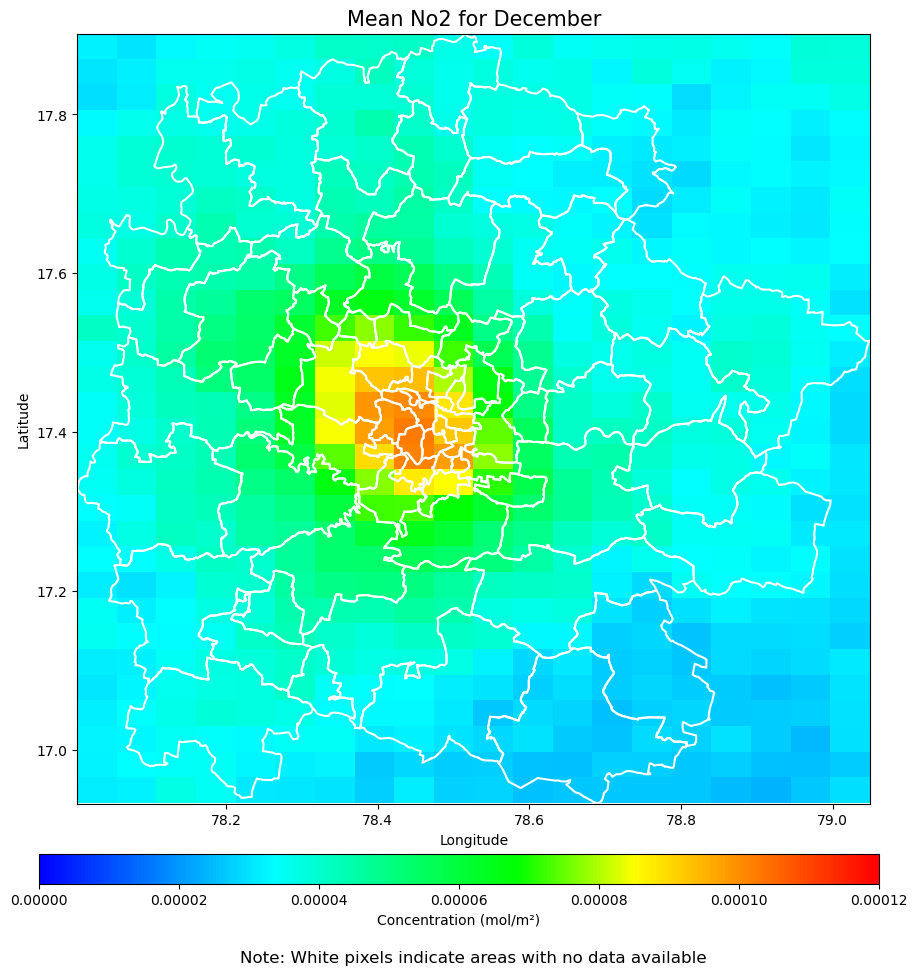
The available resolution was 15 arc second (~500m at the Equator). It was obtained through the Earth Observation group website.

# Data Preparation and Basic Analysis

Data was collected from a variety of different sources and in different resolutions. All data was available globally. The first step in processing the data was cropping it to our region of interest, the Hyderabad greater metropolitan area. This was done by specifying a bounding box using latitude and longitude coordinates ([78.00405826, 16.93264351, 79.04971836, 17.90150706]). All data was taken at the same temporal scale. This was monthly. If the temporal resolution was greater than this, it was average to monthly data.

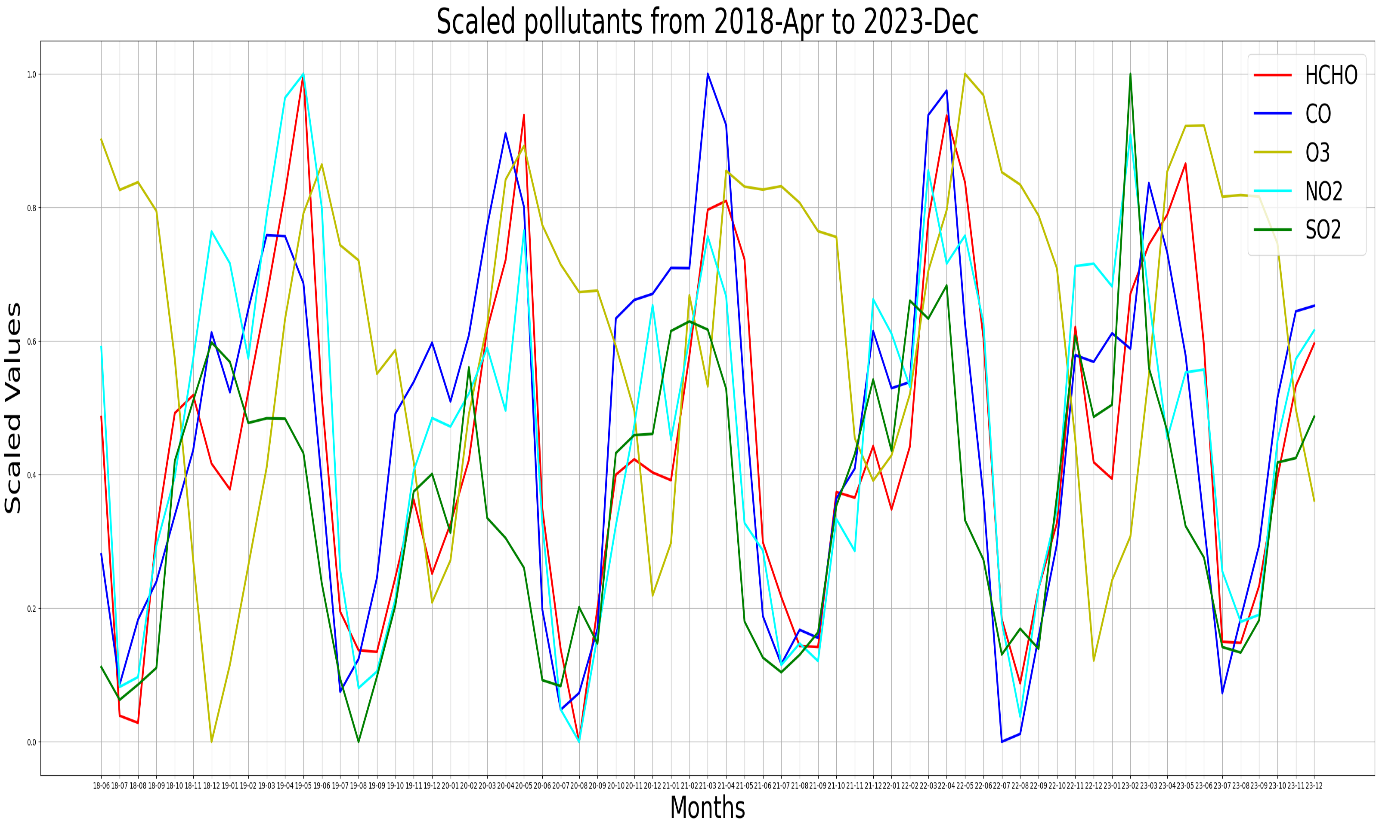
Sentinel data, NLST data, NTL data and NDVI data each had different resolutions. To compare them directly they had to be scaled up or down to the same resolution. As the region of interest was sufficiently large, and to prevent artifacts, down scaling to the lowest resolution was chosen. This was 7.5 x 3.5 km of the Sentinel data. Downscaling was done through average resampling using the rasterio python library. For each pixel in the new, coarser grid, the values of all the finer resolution pixels that fall within its bounds are averaged. This process involves computing the mean value of the finer-scale data and assigning that mean to the corresponding coarser pixel.

After the different datasets were scaled to the same resolution, they were visualised using heatmaps.



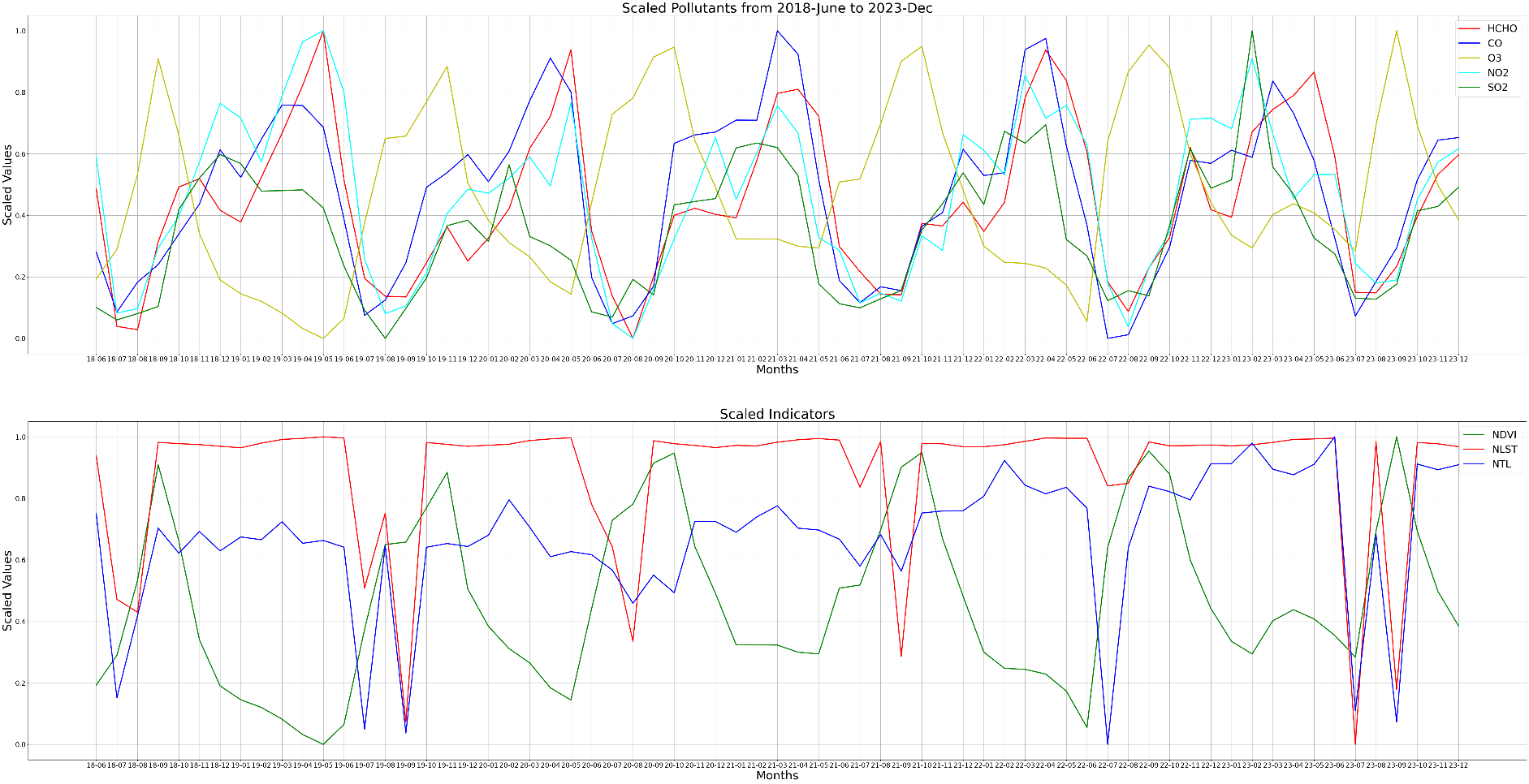
Each pollutant and indicator had a different scale and unit. To make them directly comparable, they were all scaled to values between 0 and 1.

After scaling, the average values for each month were plotted to help identify seasonal and yearly trends in both pollutants and indicators. Taking monthly averages gave a total of 67 datapoints to be plotted.



It is clear from the above graph that there is a seasonal trend in air pollution. Pollution increases on average during the winter months and falls during summer. O3 alone is slightly displaced from the other pollutants.

Comparisons were also made with the urbanisation indicators.



# Correlation Measures

After completing the basic data scaling and plotting, the next step was to analyze the relationship between the pollutants and environmental indicators using various correlation methods. The data for each variable was extracted from Geotiff file formats into corresponding two-dimensional arrays. Each element within these 2D arrays represented a specific location, defined by its latitude and longitude, for a particular month. To facilitate easier comparison across the variables, these 2D arrays were flattened into 1D arrays. This transformation allowed for the application of correlation techniques without altering the spatial relationships between the data points. For instance, when comparing CO concentrations with NLST values, the i-th element in both arrays corresponded to the same geographical location and time period, ensuring that comparisons were valid and spatially consistent.

## Spearman Correlation

Spearman correlation measures the strength and direction of a monotonic relationship between two ranked variables. Unlike Pearson correlation, Spearman does not assume that the relationship is linear or that the data is normally distributed. Instead, it assesses whether the variables tend to increase or decrease together, regardless of whether the change follows a straight line. It works by ranking the data points and then computing the Pearson correlation between the ranks. This makes Spearman more robust to outliers and more appropriate for ordinal data or when the relationship is non-linear but still monotonic (i.e., consistently increasing or decreasing).

The formula for Spearman's rank correlation coefficient ρ is:

Where:

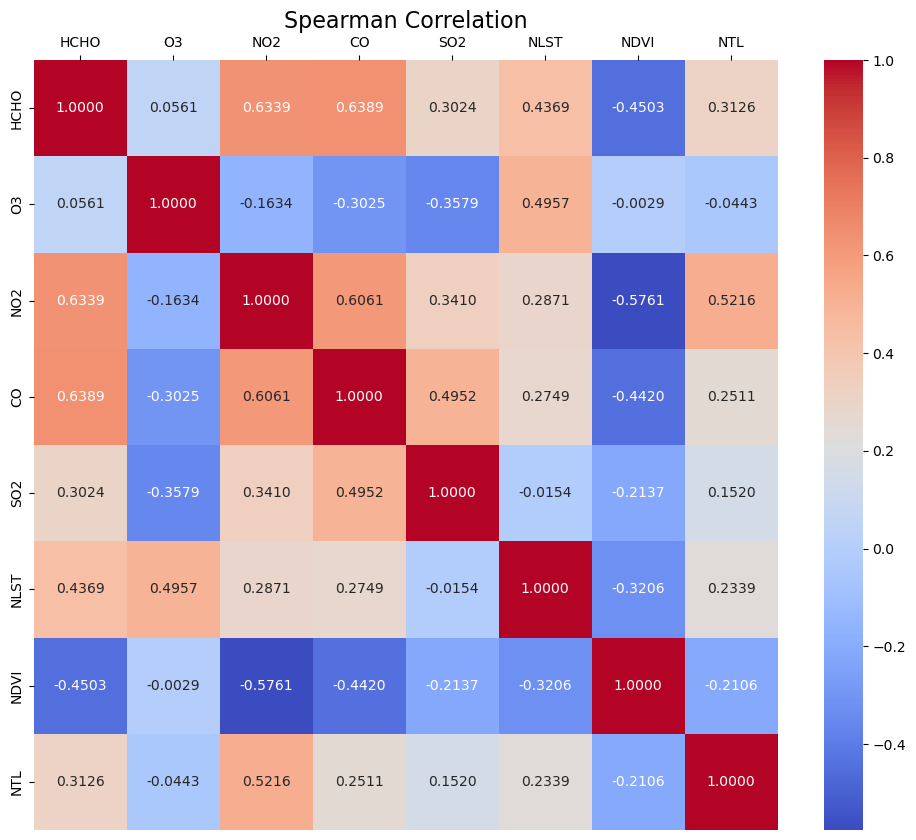
* ​ is the difference between the ranks of corresponding values of the two variables.
* is the number of data points.

Initially spearman correlation was calculated for each month individually, for each pair of pollutants and indicators. The average correlation over these individual months is given below.

Average Spearman correlation taken for each month individually:

|  |  |  |  |
| --- | --- | --- | --- |
| Pollutants | NLST | NDVI | NTL |
| CO | 0.341601 | -0.056234 | 0.025260 |
| NO2 | 0.148313 | -0.233280 | 0.547565 |
| O3 | 0.248842 | 0.070109 | -0.216006 |
| SO2 | 0.004142 | 0.003618 | 0.014581 |
| HCHO | 0.102634 | -0.090301 | 0.188029 |

It was also measured for a combined array for all 67 months(approximately 32000 values).



From the heatmap it is clear that most pollutants are positively correlated with NLST and NTL, and negatively correlated with NDVI.

## Pearson Correlation

Pearson correlation is a statistical measure that evaluates the linear relationship between two continuous variables. It quantifies how strongly the variables are related by producing a value between -1 and +1, where +1 indicates a perfect positive linear relationship, -1 signifies a perfect negative linear relationship, and 0 means no linear correlation. Pearson correlation assumes that the relationship between the variables is linear and that the data is normally distributed.

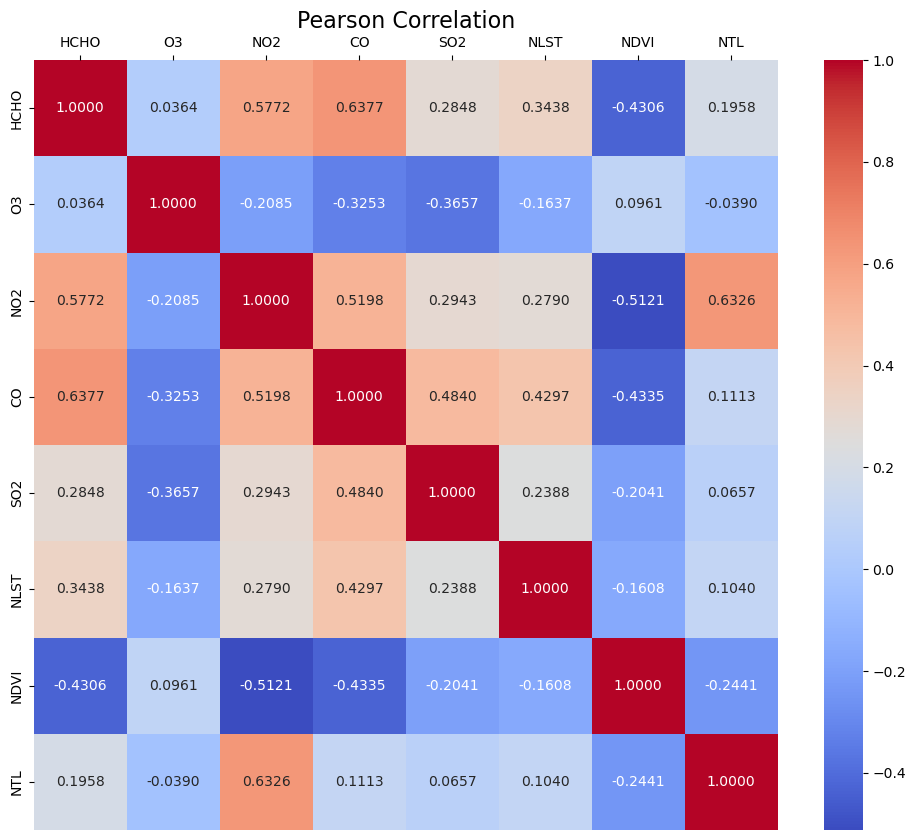
The formula for Pearson correlation coefficient r is:

Where:

* ​ and are the individual data points.
* The summation is over all data points.

Pearson correlation was also calculated on the combined array described above.

The results were similar, showing the same relationship between the pollutants and indicators.



## Multivariate Linear Regression

Multivariate Linear Regression is a machine learning technique that helps estimate a dependent variable in terms of separate independent variables. It assumes the relationship between the dependent and independent variables is linear.

For our purposes, the air pollutants were taken as the dependent variables and the indicators were considered independent variables.

The dataset used was the monthly spatial average of each pollutant and indicator, giving a total of 67 datapoints for each. All the datapoints were scaled between 0 and 1 to make them more uniform.

Using regression, the coefficients for NDVI, NLST and NTL are estimated to give a linear relationship between them and the pollutants.

Results:

HCHO = -0.4678 NDVI + 0.2586 NLST + 0.2632 NTL

O3 = 0.0562 NDVI + -0.0852 NLST + -0.1459 NTL

NO2 = -0.5805 NDVI + 0.2148 NLST + 0.2997 NTL

CO = -0.3974 NDVI + 0.2693 NLST + 0.3056 NTL

SO2 = -0.2130 NDVI + 0.0532 NLST + 0.4218 NTL

The regression was also performed on the average of all the pollutants, represented here as average air pollution.

Average Air pollution = -0.3205 NDVI + 0.1421 NLST + 0.2288 NTL

This also demonstrates a negative correlation between the air pollutants and NDVI as well as a positive correlation with NLST and NTL. This agrees with the results found by Pearson and Spearman correlation above.

## Cross Correlation

Cross-correlation is a statistical method used to measure the similarity or relationship between two time series or signals as one is shifted relative to the other. It quantifies how much one series correlates with another at different time lags, helping to identify any time delays between the two signals.

Cross correlation was also calculated on the same spatio-temporal average dataset described above.