Study the Effect of Human Activities on Air Quality of Sri Lanka Using Satellite Images (Sentinel 5P)

Kulasinghe W.M.C.J.B.1*, Ranasinghe A.K.R.N.2

[1]Student, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka

[2]Senior Lecturer, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka

chiranjeewakulasinghe@gmail.com

Abstract *Air pollution is widely recognized as a significant environmental issue, predominantly resulting from human activities. Yet, because of continued worldwide development, precisely estimating its influence is difficult. Restrictions on human activity and development caused visible effects on the atmosphere during the COVID-19 epidemic, making it a unique opportunity to examine changes in air quality. The purpose of this study is to look into the influence of the COVID-19 lockdown on air quality in Sri Lanka using data from the Sentinel-5P satellite and its Tropospheric Monitoring Instrument (TROPOMI). The study focuses on critical air pollutants such as nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). The data show a considerable decrease in pollutant concentrations during the lockdown period, showing a strong link between reduced human activity and improved air quality. Furthermore, the study looks for repeated seasonal fluctuations in each pollutant. The study underlines the need of incorporating seasonal variables when monitoring air pollution levels and attributing changes to specific elements such as lockdown measures by detecting these patterns. Understanding seasonal variability provides a holistic view of air quality dynamics, enabling for a more accurate assessment of the impact of control measures on pollution levels. The results of this study highlight the efficacy of COVID-19 lockdown measures in reducing air pollution in Sri Lanka. The large drop in pollution concentrations during the lockdown period suggests that when human activities are restricted, air quality can improve significantly. These findings provide useful assistance for policymakers and environmental organizations in developing strategies to reduce air pollution and its associated health effects in Sri Lanka in a sustainable manner.*

Keywords: air pollution, sentinel 5p, Remote sensing, COVID-19 lockdown, TROPOMI

Introduction

Air pollution is one of most prominent problem of the world. Both living beings and environment suffer because of air pollution and its bad effects. Vehicle emissions, fuel oils and natural gas to heat homes, by-products of manufacturing and power generation, particularly coal-fueled power plants, and fumes from chemical production are few main sources of human-made air pollution.

Throughout the history the air pollution level increased due to the development in many fields such as transportation, construction, technology development. But in 2019 with the COVID-19 pandemic situation people have to limit the activities, limit the development and change their normal day to day life to overcome the pandemic situation. The result was significant air pollution decline was identified during the time. (Dutta et al., 2021)

To identify the air quality difference there are two main methods. Use of ground-based air quality monitoring stations and using the new satellite technology are the two main options. Scientists and researches commonly use ground air pollution monitoring station to capture the air quality information. Sentinel-5 Precursor is an Earth observation satellite developed by ESA as part of the Copernicus Program and one of its major objectives is to monitor the air quality in the world. It is used to identify various contends include in the atmosphere such as O_3, NO_2, SO_2, CO, CH_4, and formaldehyde by using its sensor. It showed many cities throughout the globe witnessing a significant drop in air pollutants ranging between 30% and 60% during the countrywide lockdowns. (Abdelsattar, n.d.)

a. COVID-19 and its ramification on air pollution

There was a significant decline in air pollution during the COVID-19 pandemic and lockdown period. Majorly air pollution is decreased due to limited industrial and commercial activities.

Many factors contribute to air pollution in World. Road traffic, shipping emissions, home and utility building heating, industrial production, agricultural emissions, and others are some of these. Energy production from the combustion of fossil fuels or biomass is another. In addition to directly emitting pollutants (primary emissions), these sources also produce "precursor gases" that, in turn, cause secondary pollutants to be produced through atmospheric reactions.

However, in order to combat the COVID-19 pandemic situation in 2019, people must restrict their activities, limit their development, and alter their normal day-to-day lives. As a result, during the COVID-19 pandemic and lockdown period, there was a sizable decrease in air pollution. Largely because of the reduction in industrial and commercial activity, air pollution has decreased. (Dutta et al., 2021)

b. The impact of COVID-19 on air pollution in Sri Lanka

During the implementation of COVID-19 curfews, an inherent reduction in vehicular emissions occurred in Colombo, as well as in thermal power plants and select industrialized and urban areas. A close examination of the data on air quality available indicates that, with the exception of a few suspicious outlier stations whose drop occurred a week before the curfews were implemented, there was no improvement in air quality right away. Only one week after the change in wind seasonality. (Premasiri, n.d.)

c. Sentinel 5P satellite-based air quality monitoring

Sentinel-5 Precursor spacecraft with Tropospheric Monitoring Instrument (Sentinel-5P TROPOMI) was recently launched satellite and the aim of this study was to use relatively high-resolution satellite data for local air quality/air pollution monitoring and to investigate the relation of the pollutants with geographical and demographical data of the study area. It will measure globally the levels of the following key trace gases - Ozone (O_3), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Methane (CH_4) and Formaldehyde (HCHO) – as well as 3 / 9 aerosols in the Earth's atmosphere. (Kaplan & Avdan, 2020)

Objectives

Monitor the effect of the COVID 19 pandemic and lockdown time period to air pollution in Sri Lanka by analyzing satellite images.

To accomplish the main objective few sub objectives are organized. And it's very useful for identify the main air pollution contends (O_3, NO_2, SO_2, CO, CH_4) and its expansion.

Literature Review

a. Satellite Remote Sensing

Satellite remote sensing is a technology that uses specific sensors mounted on satellites to obtain information about the earth's surface. The soils, rocks, vegetation, and water bodies on the earth's surface, for instance, each absorb and reflect solar radiation in a unique way. Through the detection of electromagnetic radiation reflected or emitted from the earth's surface, these characteristics make it possible to distinguish between different earth features. (Shimizu, n.d.)

The above definition of Remote Sensing is used in a variety of disciplines, such as extraterrestrial mapping, robotics, industrial quality control, and architecture. However, earth observation and more specifically, earth observation from airborne or space borne platforms is very crucial in modern days. (Abeyratne & Ileperuma, 2006)

b. Sentinel Program

Sentinel program started in 2014/15. Based on observational data from Earth Observation (EO) satellites and ground-based data, the Copernicus program is a European initiative for the implementation of information services dealing with environment and security. In this context, ESA is specifically in charge of carrying out the Copernicus Sentinel missions and providing operational Earth observation data to the Copernicus services.

Sentinel-1 is a day-and-night, polar-orbiting, all-weather radar imaging mission for use on land and the ocean. In 2014, the first Sentinel-1 satellite was put into orbit.

Sentinel-2 is a polar-orbiting, high-resolution, multispectral imaging mission for land monitoring that provides, among other things, images of inland waterways, coastal regions, vegetation, soil, and water cover. Additionally, Sentinel-2 provides information to emergency services.

Sentinel-3 is a polar-orbiting, multi-instrument mission that will provide highly accurate and reliable measurements of factors like ocean and land surface topography, sea and land surface temperature, and ocean and land color. In 2016, the first Sentinel-3 satellite was put into orbit.

Sentinel-4. A payload called Sentinel-4 will be mounted on a geostationary-orbiting Meteosat Third Generation-Sounder (MTG-S) satellite. The mission of Sentinel-4 is to monitor the atmosphere.

Sentinel-5 is a payload that will be embarked on a MetOp Second generation satellite, also known as PostEPS. Sentinel-5 is dedicated to atmospheric monitoring.

Sentinel-5 Precursor satellite mission dedicated to atmospheric monitoring.

Sentinel-6 will offer highly accurate altimetry for measuring the height of the ocean's surface on a global scale, primarily for operational oceanography and climate research. (*Copernicus | European Environment Agency's Home Page*, n.d.)

c. Sentinel-5 Precursor and Air quality/ Pollutants monitoring system

Air pollution is a global public health risk. According to the World Health Organization (WHO), 91% of the world's population lives in areas where air quality does not meet WHO guidelines, and 4.2 million people worldwide, including hundreds of thousands of people in Europe, die prematurely each year as a result of poor ambient air quality. As a result, it's crucial to provide air quality forecasts at the global, regional, and local levels to assist public health authorities and policymakers as well as to allow those who are most vulnerable to do something to avoid exposure to pollution. Therefore, the monitoring purposes sentinel 5 satellite has launched by (ESA) European Satellite Agency. (Inness et al., 2019)

Sentinel-5 Precursor (S5p) is a low Earth orbit polar satellite system with the goal to provide data and services on ozone layer, climate, and air quality. The S5p mission is a component of the program for the global monitoring of the environment and security from space. Key atmospheric elements such as Ozone (O_3), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Carbon Monoxide (CO), Methane (CH_4), and Formaldehyde, as well as cloud and aerosol properties, will be observed by TROPOMI on a daily basis at the global level. The mission objectives of S5P are to globally monitor air quality, climate and the ozone layer in the time period between 2017 and 2023. (Ialongo et al., 2020)

d. Mechanism and methods use in Sentinel-5 Precursor

The Differential Optical Absorption Spectroscopy (DOAS) method is employed to effectively match the differential absorption cross-sections with the measured sun-normalized Earth radiance spectrum. The slant column density can be determined using this fitting procedure.

The first stage in the DOAS algorithm is to calculate the slant column density, which is the quantity of trace gas along the average path that photons inside a fit window take as they pass through the atmosphere and arrive at the satellite sensor from the sun.

To account for scattering and absorption that gradually change with wavelength, such as surface reflection and scattering by molecules, aerosols, and clouds, a polynomial function is used as a high-pass filter. The high-pass filter also eliminates other instrumental multiplicative effects as well as progressively shifting radiometric calibration mistakes.

e. Air Pollutants

- **Carbon Monoxide (CO)**

Carbon Monoxide (CO) is one of the most prevalent and widely dispersed air pollutants. It is a gas with no flavor, no smell, and little water solubility. Compared to air, carbon monoxide has a slightly lower density. It easily reacts with hemoglobin in the human body to form carboxyhemoglobin. Endogenous carbon monoxide production also occurs in small amounts. Every year, a significant number of people die in Europe and the US from carbon monoxide poisoning, which continues to be one of the main causes of accidental and suicidal poisonings.

CO is formed through incomplete burning of compounds than contain carbon such as gasoline, natural gas, oil, coal, and wood. Usually, the largest source of CO is vehicle emissions. The result is higher CO percentage at city/ town areas with higher traffic jams. And near factory sites. (Dey et al., 2019)

- **Nitrogen Dioxide (NO_2)**

In the class of gases known as nitrogen oxides, or NOX, nitrogen dioxide, also known as NO_2, is a gaseous air pollutant made up of both nitrogen and oxygen. NO_2 is produced during the high-temperature combustion of fossil fuels like coal, oil, gas, or diesel.

About half of the NOx that is released comes from vehicles and other mobile sources. Nearly 40% of the NOX emissions from stationary sources come from the boilers in electric power plants. Additionally, significant emissions are also produced by anthropogenic sources like iron and steel mills, cement plants, incinerators, gas turbines, stationary sources with reciprocating spark ignition, and diesel engines, as well as factories that make glass, cement, and nitric acid. Lightning, grass and forest fires, trees, shrubs, bushes, yeasts, and lightning are examples of biological or natural sources of nitrogen oxides. (*What Is Ozone? | US EPA*, n.d.)

- **Ozone (O_3)**

Ozone is a chemical that is highly oxidative and is created in the lower atmosphere from gases, many of which come from anthropogenic sources. This chemical is created through photochemistry that is fueled by solar radiation.

O_3 causes a rise in mortality and respiratory morbidity. O_3 appears to have effects independent of other air pollutants like particulate matter in short-term studies on respiratory symptoms, lung permeability, lung inflammation, pulmonary function, increased medication use, morbidity, and mortality (PM). (*What Is Ozone? | US EPA*, n.d.)

By the turn of the century, O_3 will cause significant problems with global air pollution. The outcomes of the most recent scenario analysis and modelling work highlight the crucial part emissions controls play in predicting future O_3 concentrations. They also demonstrate that by 2050, local and regional ground-level O_3 may be significantly impacted by climate change.

f. COVID lockdown effects on Global Air pollution

This study highlights the dynamics of NO_2 pollution throughout the transition from normal conditions to the COVID-19 outbreak period. This period is distinguished by a transient decrease in traffic intensity and industrial activity, resulting in a large fall in tropospheric

NO_2 column number density. In several large European cities, the drop reached as much as 85%. The validation of satellite-derived data was accomplished using cross-correlation analysis with independent ground-based observations. The results showed encouraging correlation values (R2) ranging between 0.5 and 0.75 across different regions. The considerable reduction in NO_2 emissions during the COVID-19 lockdown was further supported by Industrial Production Index statistics and air traffic volume records. (Vîrghileanu et al., 2020)

g. COVID lockdown effects on Air pollution Of Sri Lanka

The study looks on the influence of the COVID-19 shutdown in Sri Lanka on air pollution levels in Colombo and Kandy. Carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and particle matter (PM10, PM2.5) are all examined. The data show a decrease in daytime PM10, PM2.5, CO, and NO_2 concentrations in both cities during the lockdown period. Notably, NO_2 was the most susceptible to the lockout measures. Conversely, O_3 concentrations increased over this time period, implying a decrease in NOx emissions and, as a result, lower O_3 titration by NO. These findings give light on the impact of COVID-19 regulations on air quality in Sri Lankan cities. (Pushpawela et al., 2023)

h. Factors which effect for air pollution

Air pollution due to several environmental and physical factor. Temperature, air pressure , seasonal changers, human activities are few of those.

- **Temperature variation effects on Air**

While the effect of temperature on airborne pollutants is well known, the exact impacts of temperature rise during heatwaves on air pollution remain unknown. The link between ozone (O_3), particulate matter (PM10), nitrogen dioxide (NO_2), and temperatures in Birmingham's urban and rural areas was investigated using regression analysis. The investigation found that during heatwaves, all pollution levels increased at each site, with the peak of O_3 and PM10 occurring at the same time as the greatest temperature observed. These findings show that the influence of temperature on air pollution remains consistent regardless of whether the location is rural or urban, despite the fact that concentrations of air pollutants (O_3, NO_2, and PM10) significantly increased with rising temperatures, particularly during heatwaves. (Kalisa et al., 2018)

- **How Air pressure effects for the air components**

A control measurement was performed to assess the consistency of readings between two locations 35 meters apart that had varied levels of particulate matter (PM). The purpose of this control measurement was to validate the consistency of measurements received from both sensors, which was confirmed by the observed trends of the measured quantities. The researchers discovered instances of significant association, indicating a close relationship, between PM10 levels and climatic parameters such temperature, humidity, and barometric pressure. However, no correlation was found in several circumstances, most likely due to the influence of wind, which was not examined in this study. (Kirešová et al., n.d.)

- **How Seasonal changers effects for the air components**

The varied characteristics of the seasons influence seasonal variance in air pollution, particularly during the summer and winter seasons, which are generally referred to as "heating" seasons. Climate trends, shifting atmospheric conditions, daily weather variations, and human activities all contribute to greater levels of air pollution in specific months throughout the year. These factors all contribute to the varying levels of air pollution reported at various times. The study makes use of data acquired from an automated immission measurement station in Eastern Wielkopolska over a seven-year period (2009-2015). The investigation focuses on the average and highest levels of air pollution. (Liao et al., 2020)

Methodology

Satellite data collection and filtering was done by using Google Earth Engine. Sentinel 5p satellite data was accessible in Copernicus open access hub and Earth Engine data catalog.

Step1

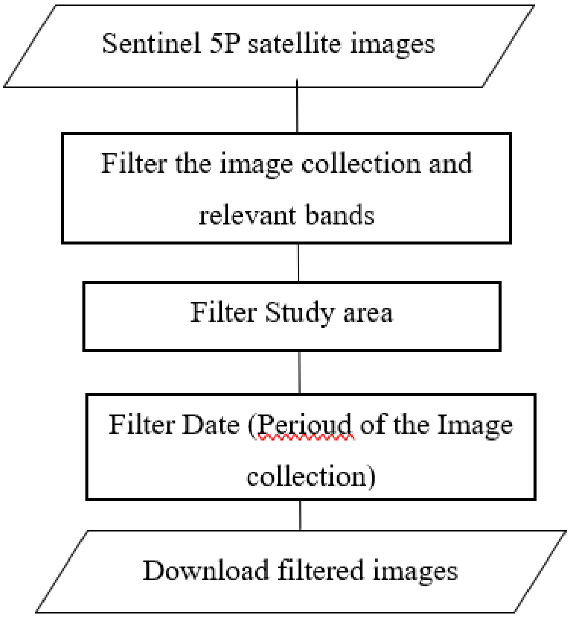

Figure 1: Methodology Step1

Step 2

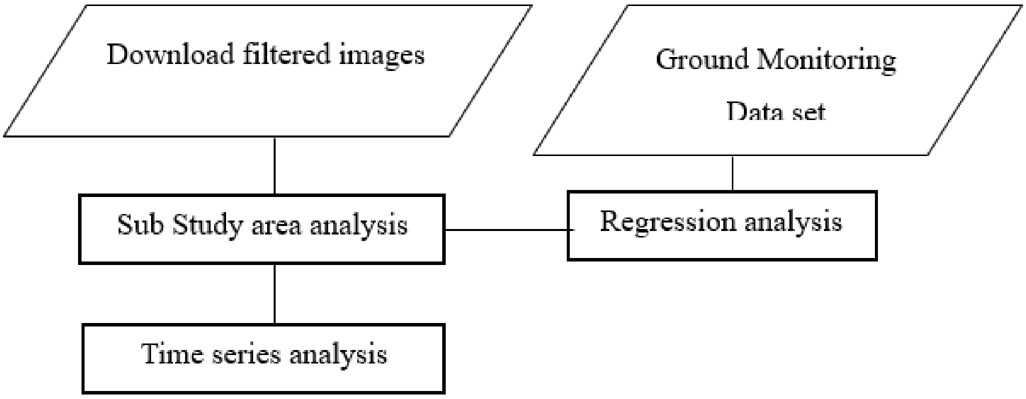

Figure 2 : Methodology Step 2

a. Preprocessing and algorithms are used for recognition of pollutants

For each component TROPOMI has developed different algorithms or developed existing algorithms. Cloud masking is not necessarily due to it is a instrument with four hyperspectral channels and able to capture from the Ultraviolet wavelength range into the short-wave infrared spectrum to detect atmospheric constituents, clouds and aerosols.

TROPOMI Level 2 data products that are generated within the Copernicus ground system which are available in the Earth data catalogue. Level-2 products are geophysical values obtained by processing measurement data in the Level-1B product. therefore, the correction is already completed for TROPOMI level 2 data.

Table 1: TROPOMI dataset

Product type	Parameter	User Documents
L2__O3____	Ozone (O_3) total column	PRF-O3-NRTI, PRF-03-OFFL, PUM-O3, ATBD-O3, IODD-UPAS
L2__O3_TCL	Ozone (O_3) tropospheric column	PRF-03-T, PUM-O3_T, ATBD-O3_T, IODD-UPAS
L2__O3__PR	Ozone (O_3) profile	PRF-O3_PR, IODD-NL, PUM-O3_PR, ATBD-03_PR
L2__NO2___	Nitrogen Dioxide (NO_2), total and tropospheric columns	PRF-NO2, PUM-NO2, ATBD-NO2, IODD-NL
L2__SO2___	Sulfur Dioxide (SO_2) total column	PRF-SO2, PUM-SO2, ATBD-SO2, IODD-UPAS
L2__CO____	Carbon Monoxide (CO) total column	PRF-CO, PUM-CO, ATBD-CO, IODD-NL
L2__CH4___	Methane (CH_4) total column	PRF-CH4, PUM-CH4, ATBD-CH4, IODD-NL

L2__HCHO__	Formaldehyde (HCHO) total column	PRF-HCHO, PUM-HCHO , ATBD-HCHO , IODD-UPAS
L2__CLOUD_	Cloud fraction, albedo, top pressure	PRF-CL, PUM-CL, ATBD-CL, IODD-UPAS
L2__AER_AI	UV Aerosol Index	PRF-AI, PUM-AI, ATBD-AI, IODD-NL
L2__AER_LH	Aerosol Layer Height (mid-level pressure)	PRF-LH, PUM-LH, ATBD-LH , IODD-NL
UV product[1]	Surface Irradiance/erythemal dose	-
L2__NP_BDx, x=3, 6, 7 [2]	Suomi-NPP VIIRS Clouds	PRF-NPP, PUM-NPP, ATBD-NPP
AUX_CTMFC AUX_CTMANA	A-priori profile shapes for the NO2, HCHO and SO2 vertical column retrievals	PUM

b. Earth Engine (GEE) Data Catalog

A wide and varied selection of geospatial datasets and satellite imagery are available for exploration and analysis within the Google Earth Engine platform through the Google Earth Engine (GEE) Data Catalog. It acts as a central access point for a variety of data from numerous sources, such as satellite missions, climate models, and various geographic data suppliers.

c. Google Earth Engine

Google built Google Earth Engine (GEE), a potent geospatial analytic platform that combines an extensive collection of satellite imagery and geospatial datasets with modern computer capacity. It is a useful tool for monitoring the environment, analyzing land cover, modeling ecosystems, and researching climate change since it enables users to access, analyze, and visualize petabytes of global-scale Earth observation data.

Processing and analyzing huge amounts of geospatial data in a cloud-based setting is one of Google Earth Engine's primary advantages. Users can carry out intricate geographical analysis without the requirement for specific gear or software by making use of Google's enormous computational infrastructure.

d. Filtering and Downloading the Images / Datasets

Google Earth Engine collaborated with Java Script API and using JS the filtering part was completed. JS code is used to filter the images and the data set according to the needs. Using the codes, the dataset was filtered using different parameters such as period, image collection, band name, resolution. First the image collection and the band were selected. The imported boundary file was applied to clip the data only for study area. Image collection was used because it helps to get a mean value, eliminate redundancies and to improve the resolution of the final data set (images).

The Google Earth Engine platform was used to carry out the necessary procedures as part of the research approach used in this study. JavaScript code was meticulously written to export the final product as a TIFF file. Notably, the for-loop function was critical in enabling the efficient download of the entire dataset. This resulted in a more streamlined and efficient approach. The link with Google Drive ensured the files' accessibility, allowing for easy recovery and further analysis. Prior to beginning the downloading process, critical details such as the appropriate coordinate system, file path, resolution, and scale parameters were carefully specified.

e. Statistical Analysis

To conduct a thorough investigation, each research region was submitted to a statistical comparison based on the data recovered from the TIFF image. The necessary datasets were methodically retrieved from the TIFF image, ensuring the inclusion of all relevant components. Statistical comparisons were carried out for each component, which included a variety of quantitative indicators and metrics. This rigorous technique allowed for a full review of the research areas, providing significant insights into their respective characteristics, and permitting relevant comparisons.

f. Study Area

Geographically, the country is located between 5°55' and 9°51' North latitude and 79°42' to 81°52' East longitude. The island of Sri Lanka has a total land size of 65,610 square kilometers, and it extends over a 432-kilometer span from Point Pedro in the north to

Dewundara Head in the south. In a similar vein, Sri Lanka's width is roughly 224 kilometers from Colombo on the western coast to Sangaman Kanda point on the eastern.

- **Sub Study Areas**

For the better understanding and for better visualization several sub study areas were used according to their specific characteristics.

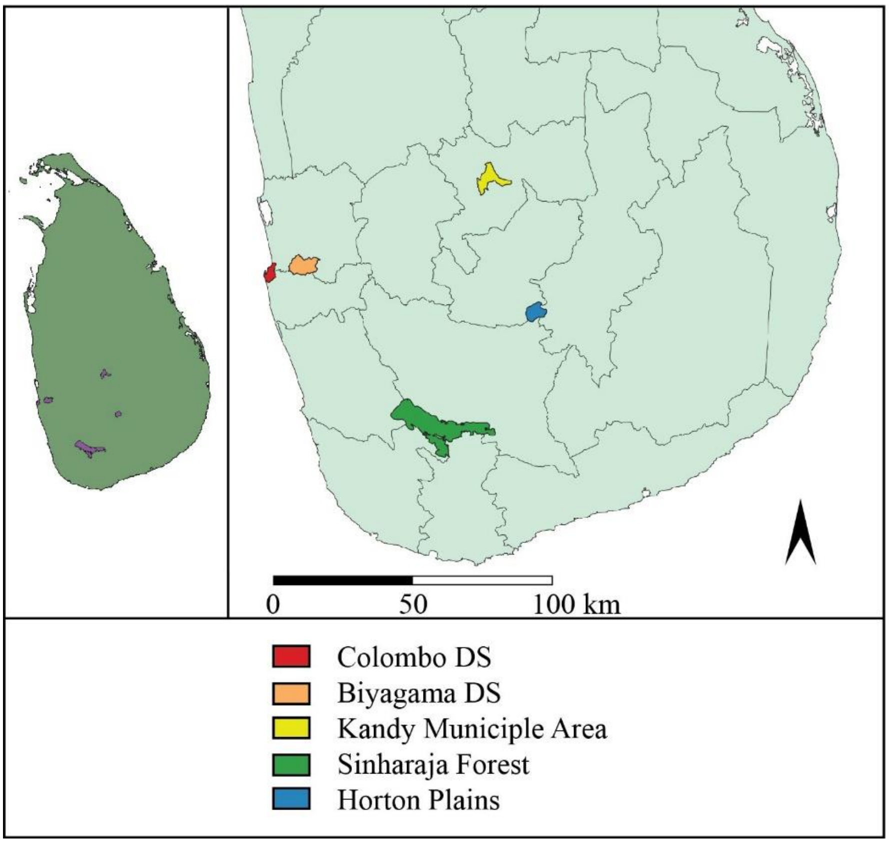

Figure 3: Study Area

Table 2: Sub Study Areas and its Importances

Sub Study Area	Important
Colombo DS	Colombo is the largest city on the west coast of Sri Lanka and acts as its commercial capital city. About 70% of Colombo's air pollution is caused by vehicle emissions, making vehicles the main source of the problem. Many of these cars have an average age of more than fifteen years.

	They are not equipped with the most recent equipment that filters exhaust fumes and keeps several hazardous gases from entering the atmosphere at that age.
Biyagama DS	The Biyagama Export Processing Zone has a total area of 450 acres and is operating at full capacity. The zone employs over 25,000 workers and hosts 58 manufacturers. Most are in the garments and rubber sectors.
Kandy Municipal Area	Kandy, located in Sri Lanka's central province, faces serious air pollution challenges attributed to its mountainous terrain. The city's geographical features hinder the escape of air pollutants, leading to their accumulation within the area. Due to these unique geographical circumstances, efforts must be made to address and mitigate the air pollution problem in Kandy.
Sinha raja Forest	Sinha raja is the country's last viable area of primary tropical rainforest. It also recognized a world heritage site by UNESCO
Horton Plains	Horton Plains National Park is a national park in the central highlands of Sri Lanka. It has the cleanest water and air in the country according to the researches

g. Remotely sensed satellite data (SENTINEL 5P).

The Copernicus mission of the European Space Agency includes the Sentinel-5P satellite, which is orbiting the planet in a polar orbit. On average, it completes a full orbit every 100 minutes, equating to 14.1 orbits each day. The satellite's orbit enables it to monitor atmospheric composition and air quality globally throughout of a 24-hour period, providing coverage of the entire planet's surface.

Table 3 : Details of Sentinel 5p satellite bands

Component	**Band**	**Description**	**Resolution (m)**
CO	CO_column_number_density	Vertically integrated CO column density.	1113.2
NO_2	NO2_column_number_density	Total vertical column of NO_2 (ratio of the slant column density of NO_2 and the total air mass factor)	
O_3	O3_column_number_density	Total atmospheric column of O_3 between the surface and the top of atmosphere	

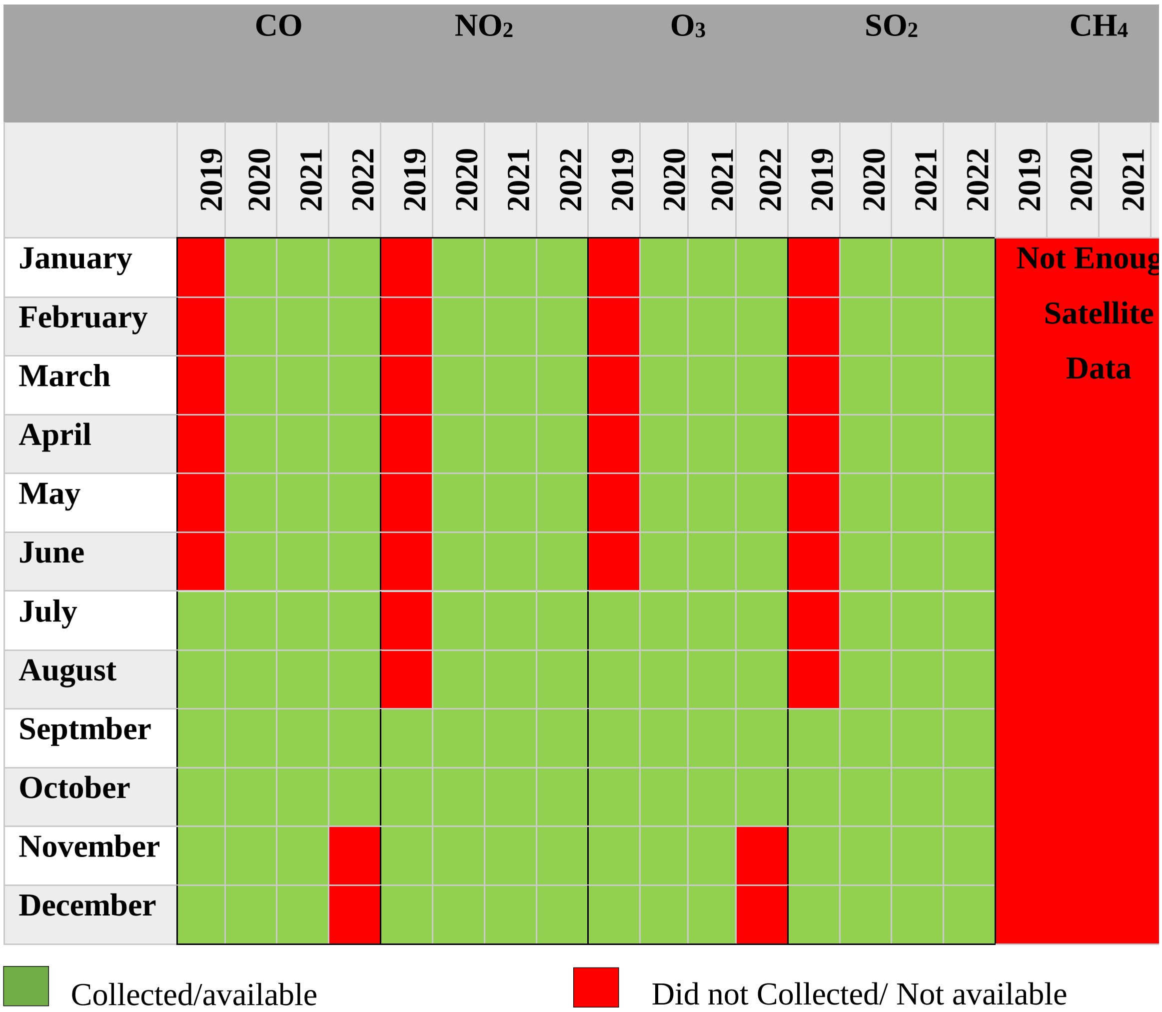

Figure 4 : Data acquisition Chart

h. Ground monitoring systems

Ground based monitoring data was using by using NBRO and Central Environmental Authority. data was available for all the components but data set was not continuous. Some data are not collected due ti various reasons. According to comparison none of the data sets were not completed.

Results and Discussion

a. Expansion of Air Pollutions

The image collection for a particular time frame contained some data redundancies, requiring a reduction in the amount of data. To do this, a mean value of the satellite photos was employed, and this problem has emerged even when using different image bands. The image collection approach was used to fix this issue. 10–14-day average time period was used for the image collection.in this case Google Earth Engine (GEE) was used and it is a great asset in this area because it is capable of managing enormous datasets online and producing the appropriate results. for the image filtering process GEE was used. Furthermore, GEE permits resolution reduction by overlaying satellite picture collections. Both of these procedures were used on all other satellite photos of each component.

- **Spatial variation in Nitrogen Dioxide (NO_2) Concentration**

In order to determine the NO_2 concentration NO2_column_number_density band was used in Sentinel 5P TROPOMI satellite images. The image and data filtering process was done.

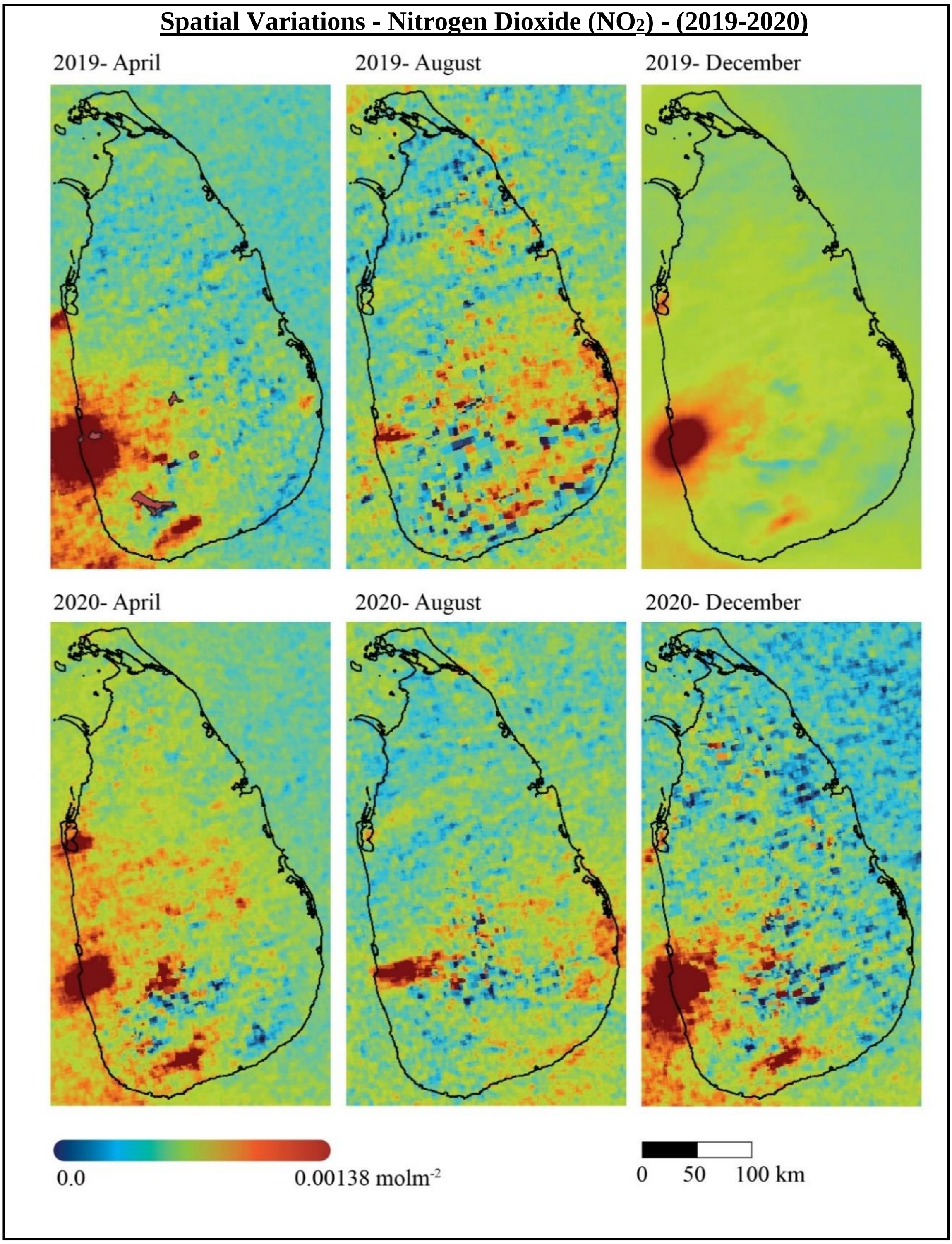

Figure 5: Spatial variation in Nitrogen dioxide (2019-2020)

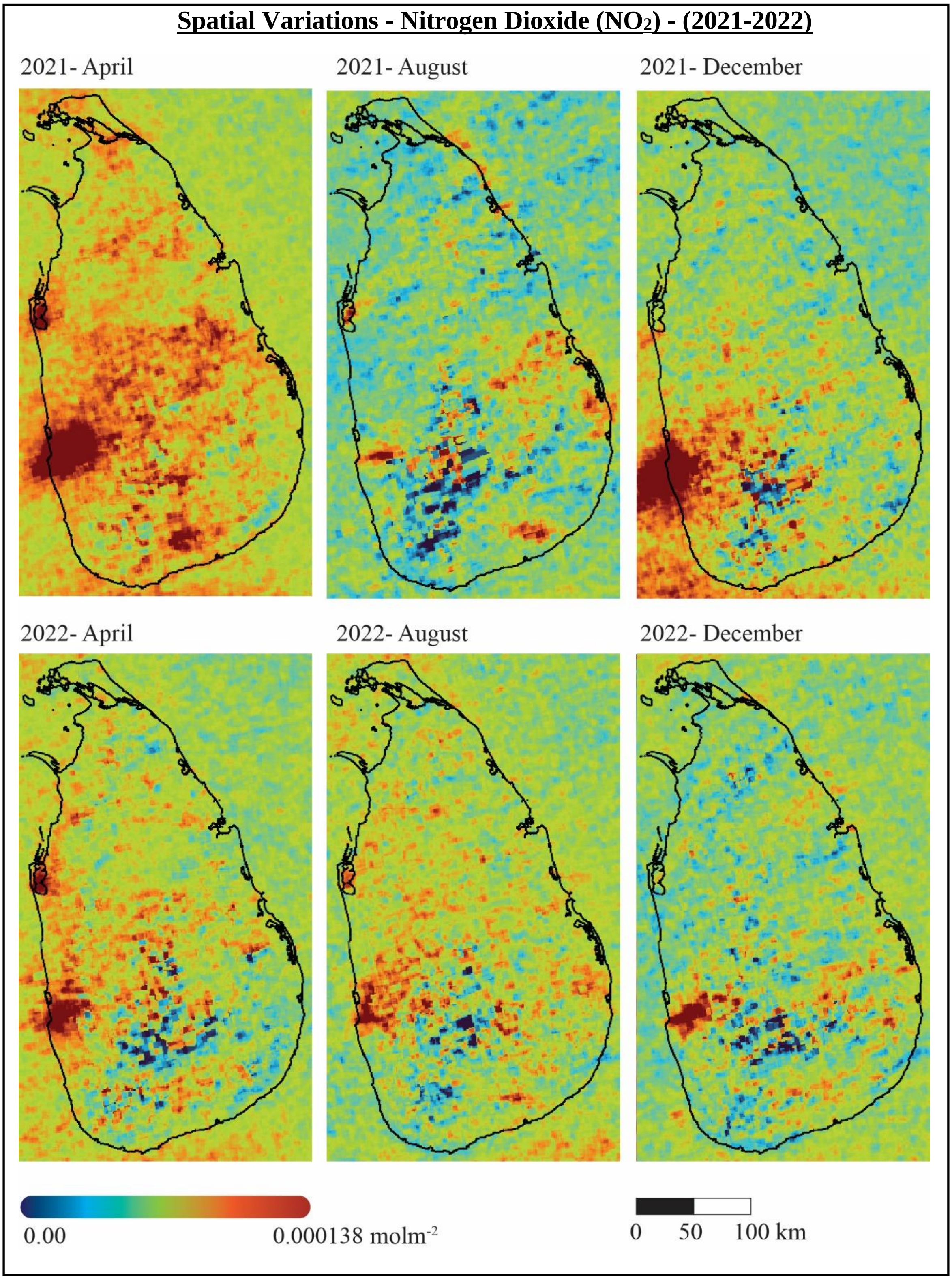

Figure 6 Spatial Distribution in Nitrogen Dioxide (2021-22)

Figures illustrate the NO_2 column number density generated from Sentinel-5P over the Sri Lanka From 2019 to mid of 2022. Respective satellite band describes the density. Each individual maps shows the monthly variation of the air pollutant between 2019 to 2022 end. During the first lockdown (March-April) time period it indicates a significant reduction in the NO_2 density in Sri Lanka. In the figure it shows significant change in 2020 April compared to April months of 2021,2022. There was another significant drop in NO_2 in 2020 October. The second longest lockdown was activated on this period. But same result was shown in 2021 and 2022 also.

- **Spatial Variations in Carbo Monoxide (CO) Concentrations**

In order to determine the CO concentration CO_column_number_density band was used..

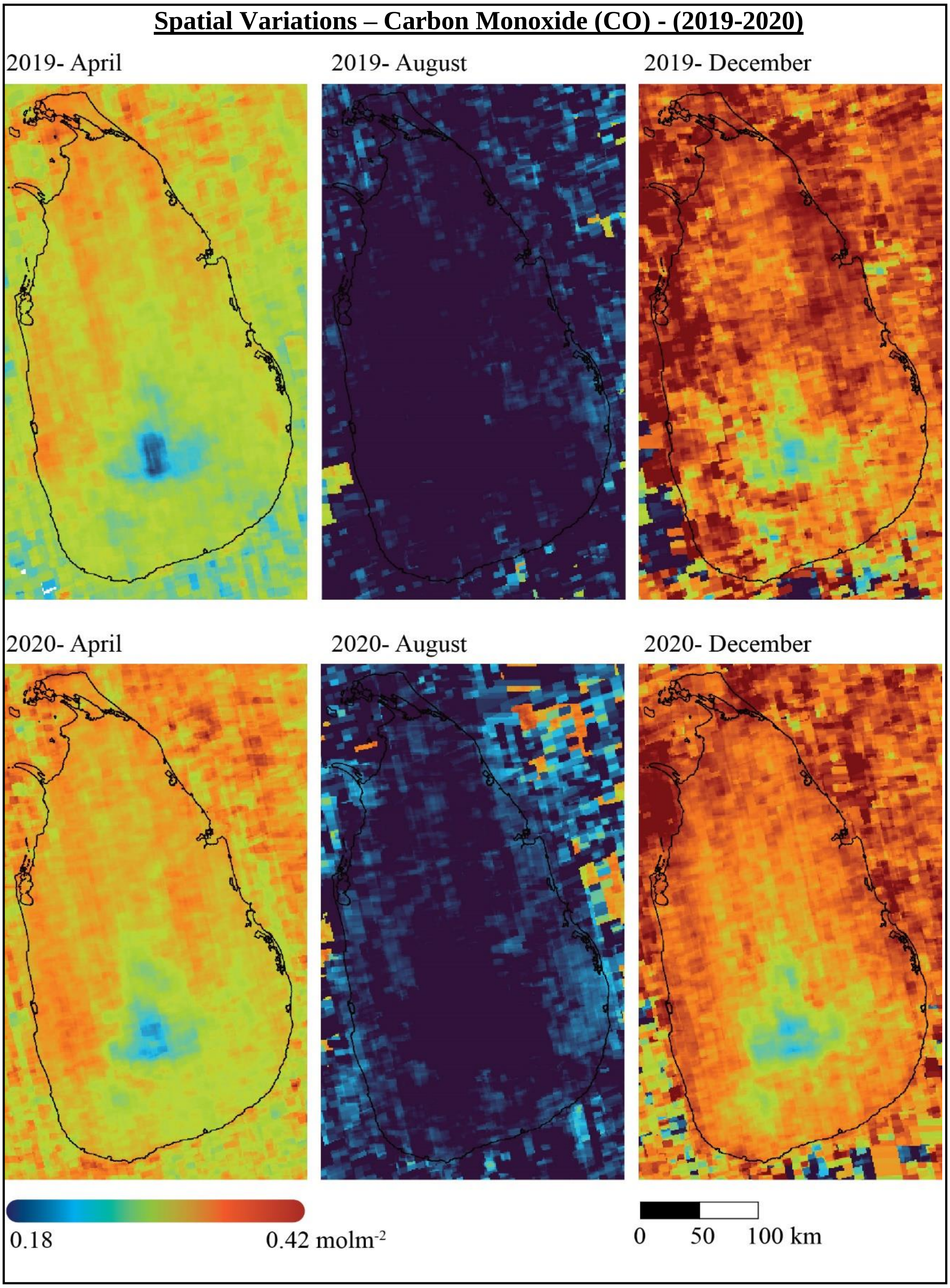

Figure 7: Spatial Distribution of Carbon Monoxide (2019-20)

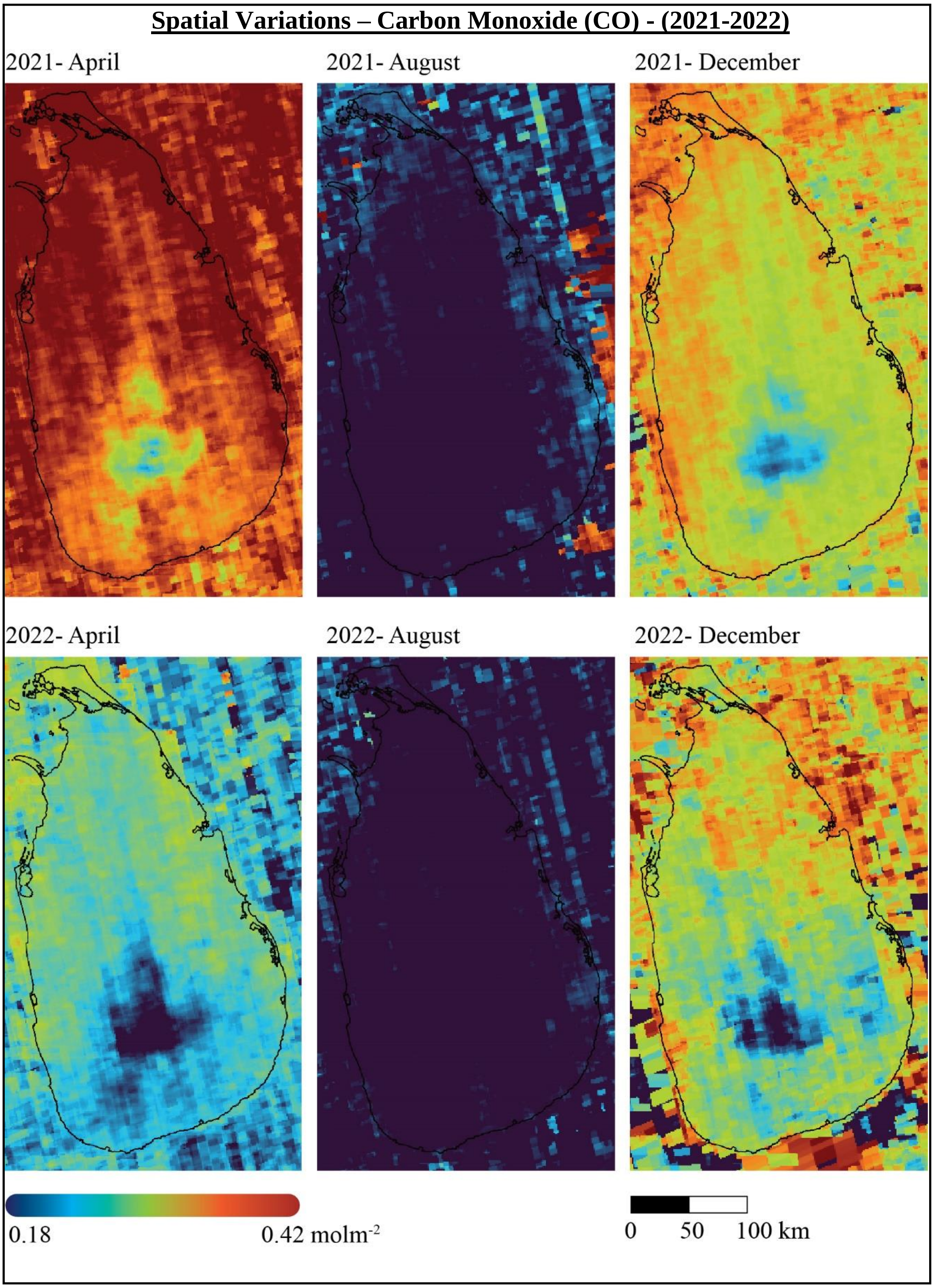

Figure 8: Spatial Distribution of Carbon Monoxide (2021-22)

Figures show the column number density of carbon monoxide (CO) generated from Sentinel-5P satellite observations over the Sri Lanka geographical region from 2019 to the middle of 2022.visual representation of the images shows two variable changing within the time period. Seasonal change and elevation change are those two factors.

- **Spatial Variations in Ozone (O_3) Concentrations**

In order to determine the Ozone (O_3) concentration O3_column_number_density band was used.

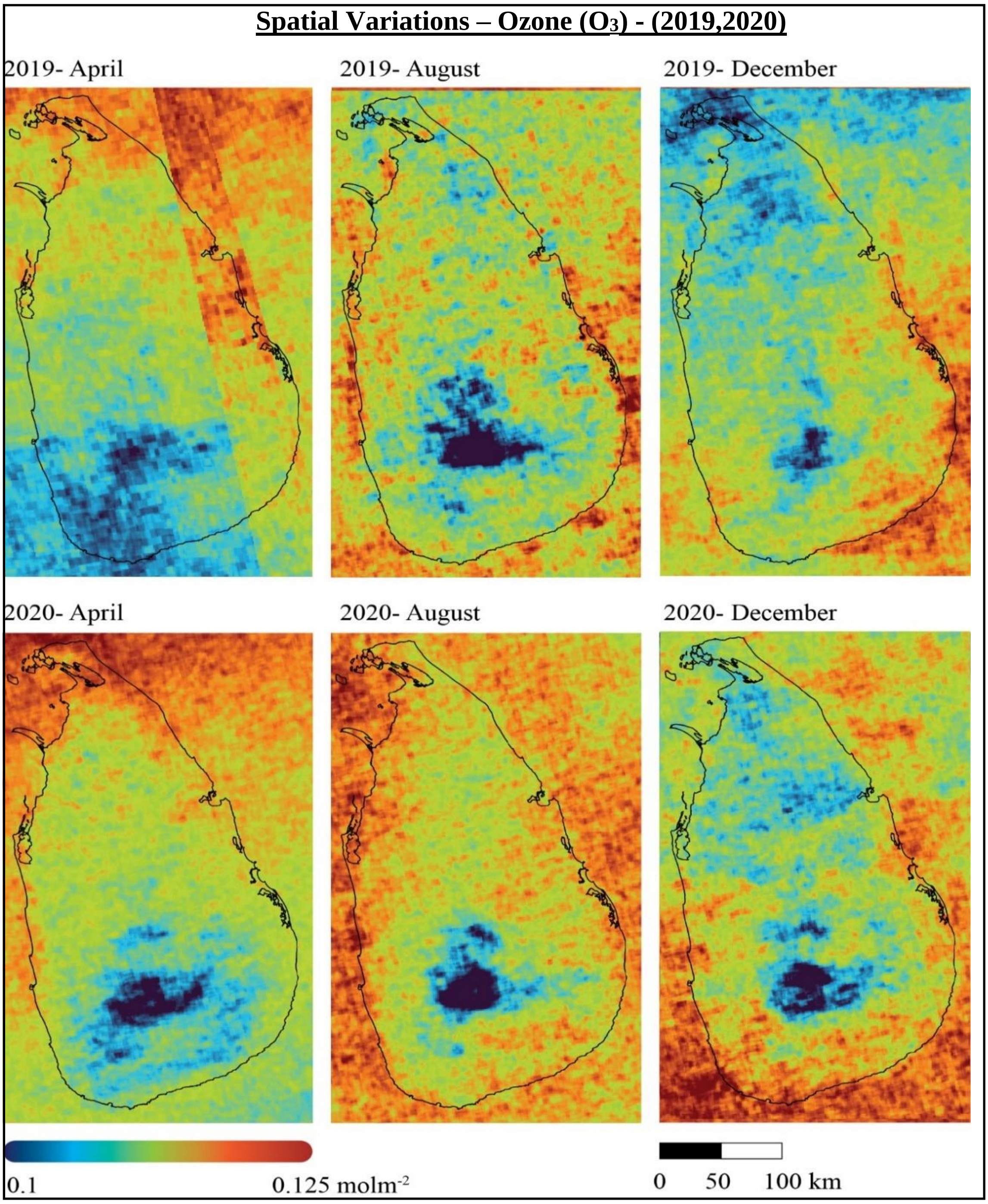

Figure 9:Spatial Distribution of Ozone (2019-20)

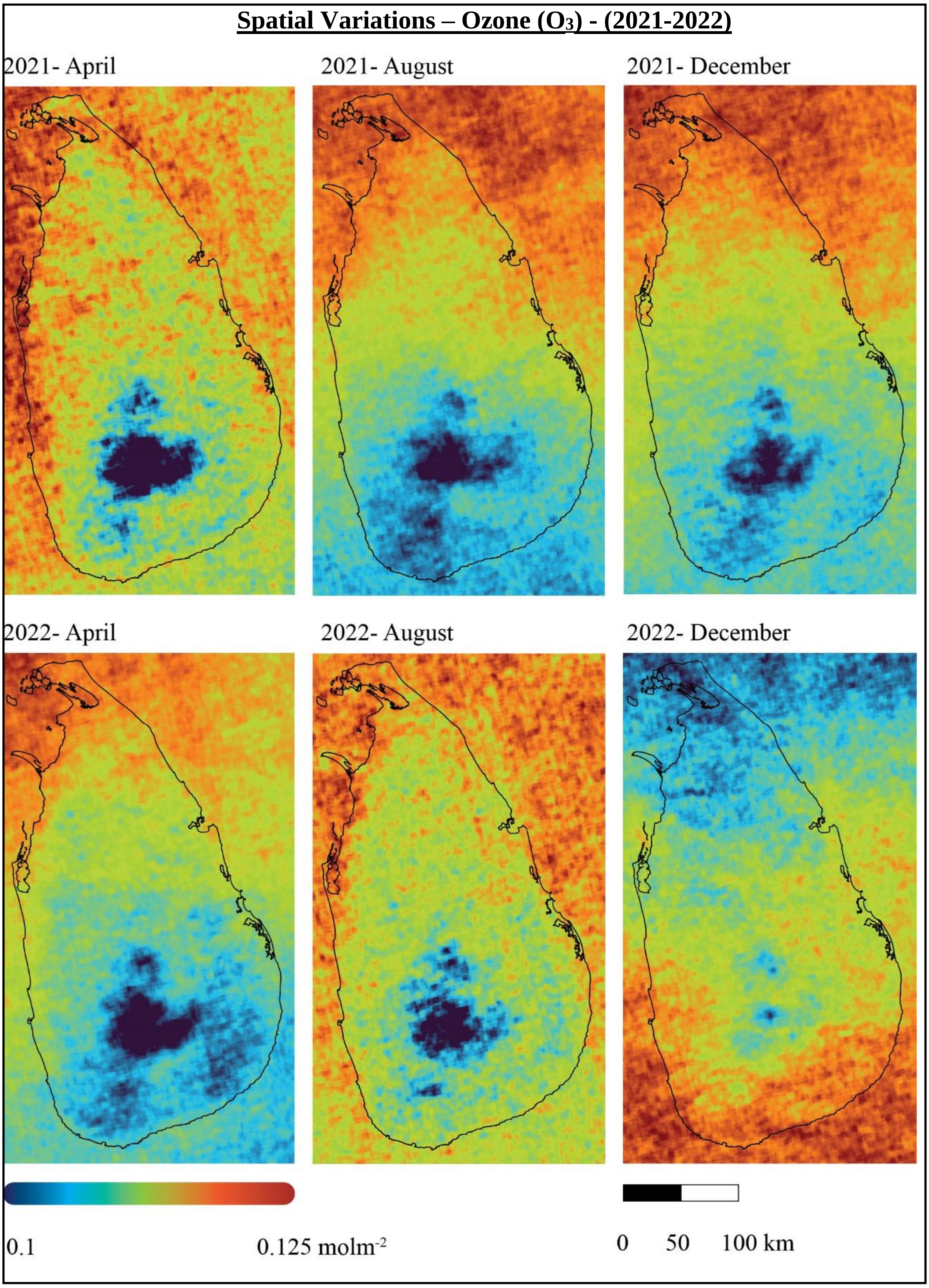

Figure 10:Spatial Distribution of Ozone (2021-22)

b. Statistical analysis based on each component

According to the methodology statistical analysis done for each component. It describes the small variation of the data set precisely. In this case each component variation within the time frame was analyzed.

Major lockdown periods of the country have been identified according to the historical data of Sri Lanka lockdown. There are two major COVID-19 lockdown period was identified in Sri Lanka.

- 2020 – April
- 2020 – October

- **Timeline of Component variation**

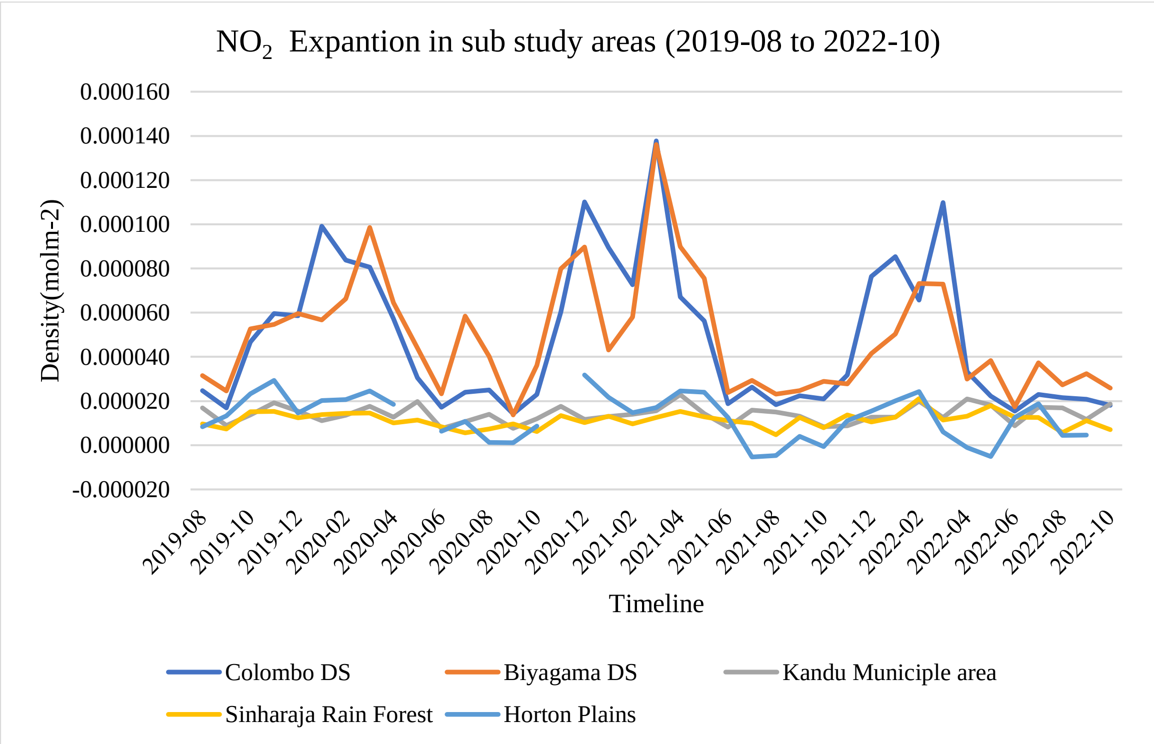

Figure 11: Nitrogen Dioxide variation according to sub study areas

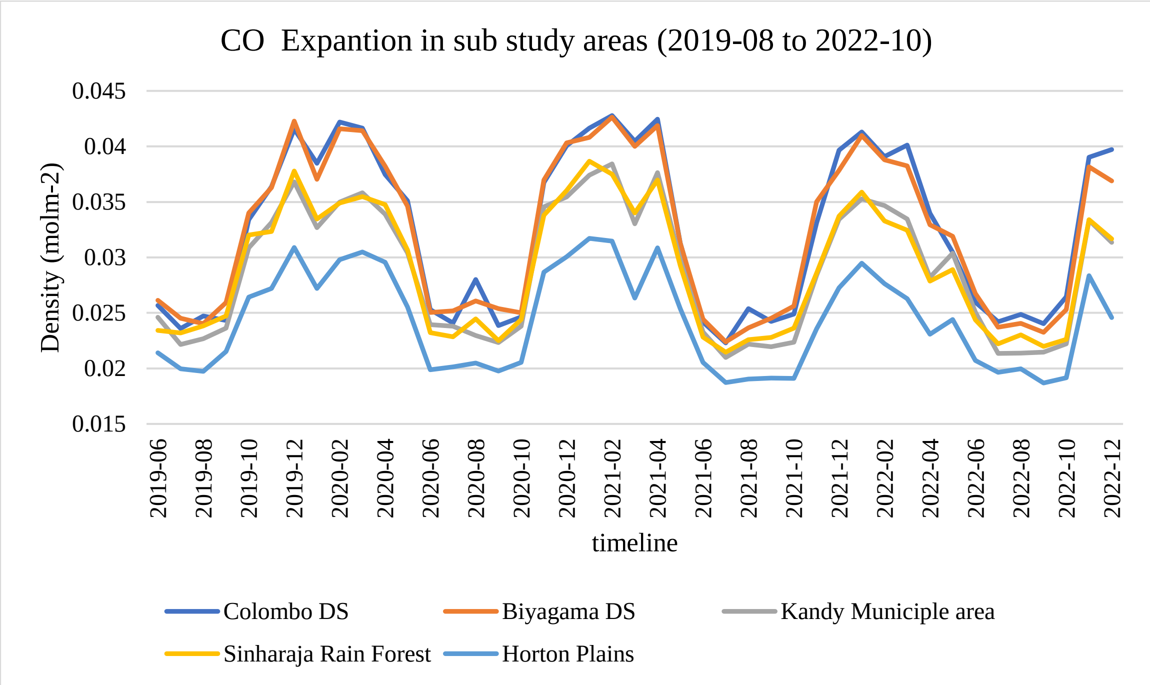

Figure 12: Carbon Monoxide variation according to sub study areas

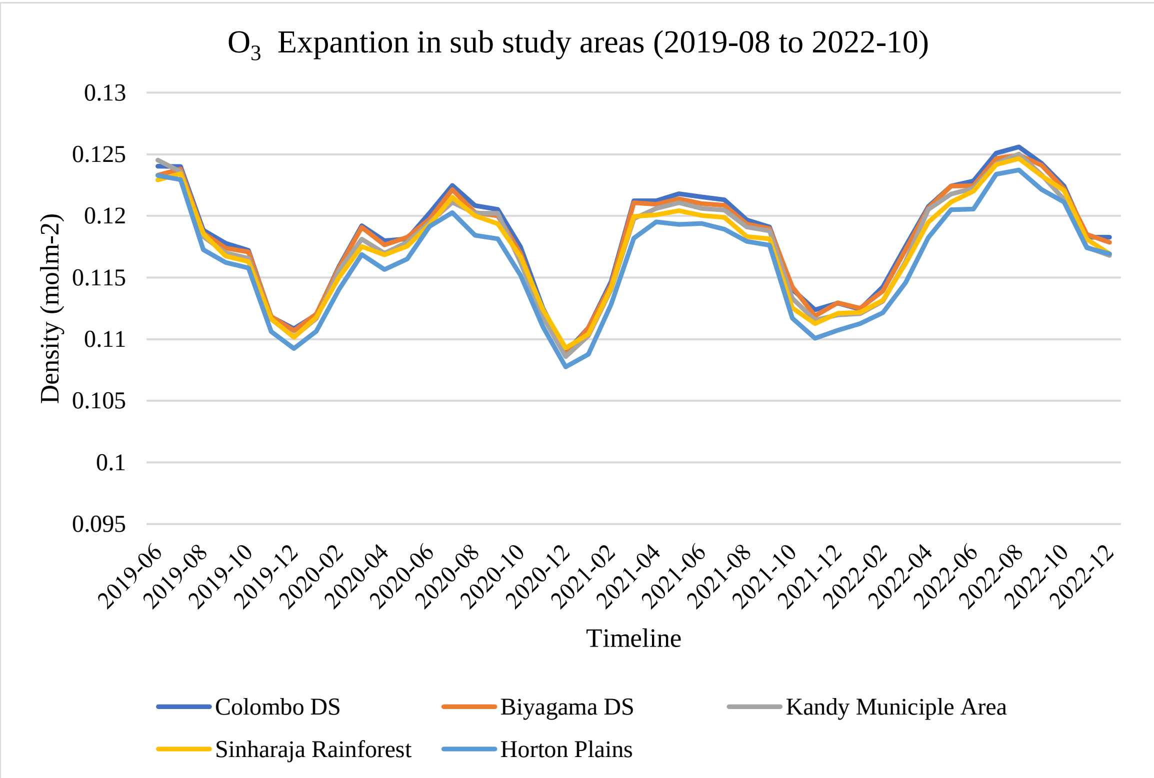

Figure 13: Ozone variation according to sub study areas

- **NO_2 expansion and variation**

According to the above graphs a significant pattern is able to identified. Let's compare each component according to the graph. During the first lockdown (March-April) time period it indicates a significant reduction in the NO_2 density in Sri Lanka. According to the data gathered by analyzing the sub study it conforms the reduction. In the figure it shows significant change in 2020 April compared to April months of 2021,2022. There was another significant drop in NO_2 in 2020 October. The second longest lockdown was activated on this period. But same result was shown in 2021 and 2022 also.

- **CO expansion and variation**

Seasonal variation

CO shows strong relationship with seasons of the year. The actual factor effects for the variation are the temperature. (Figure 12) shows that CO reaches its maximum value around December and January months. The temperature lowers dramatically in these months compared to the other months, and CO density becomes low around August and July. Which has higher temperature.

Elevation variation

The air pressure drops as elevation rises. The density of gases is affected by the decrease in pressure. In general, when you climb to greater elevations, the air becomes less thick. As a result, because carbon monoxide is lighter than air, it becomes less dense at higher heights. (Figure 12) Graph shows the variation of the study areas. According to that highest Colombo, Biyagama has the highest CO density. Those sub study areas have the lowest elevation. And Horton plains shows the lowest CO value and it has the highest elevation.

How Lockdown effects on CO

(Figure 12) shows the CO density variation during the major lockdown time period. (April & October, 2020). According to that 2022 April and October has the lowest CO value. Which means CO emission has direct relationship with the lockdown. Study area wise there has a small changing range. In terms of the study area, all six sub study areas has relatively small range of variation.

- **O_3 expansion and variation**

The data provided by the sentinel 5P images are not filtered for outer community. According to the figures it varies with elevation, seasonally and latitude wise.

Factors effect for O_3 variations

Ozone behaves completely different from the other gases previously analyzed. (Figure13) shows that ozone has highest density on August July phase and it has the lowest density at December January phase. NO2 and ozone has balance relationship. Due to lower emission of the NO2 at lockdown period ozone variation is also decrease.

c. Analysis for the April and October months.

According to the lockdown history if the Sri Lanka majority of the country 2020-April and 2020-October months has been a complete COVID-19 lockdown period.

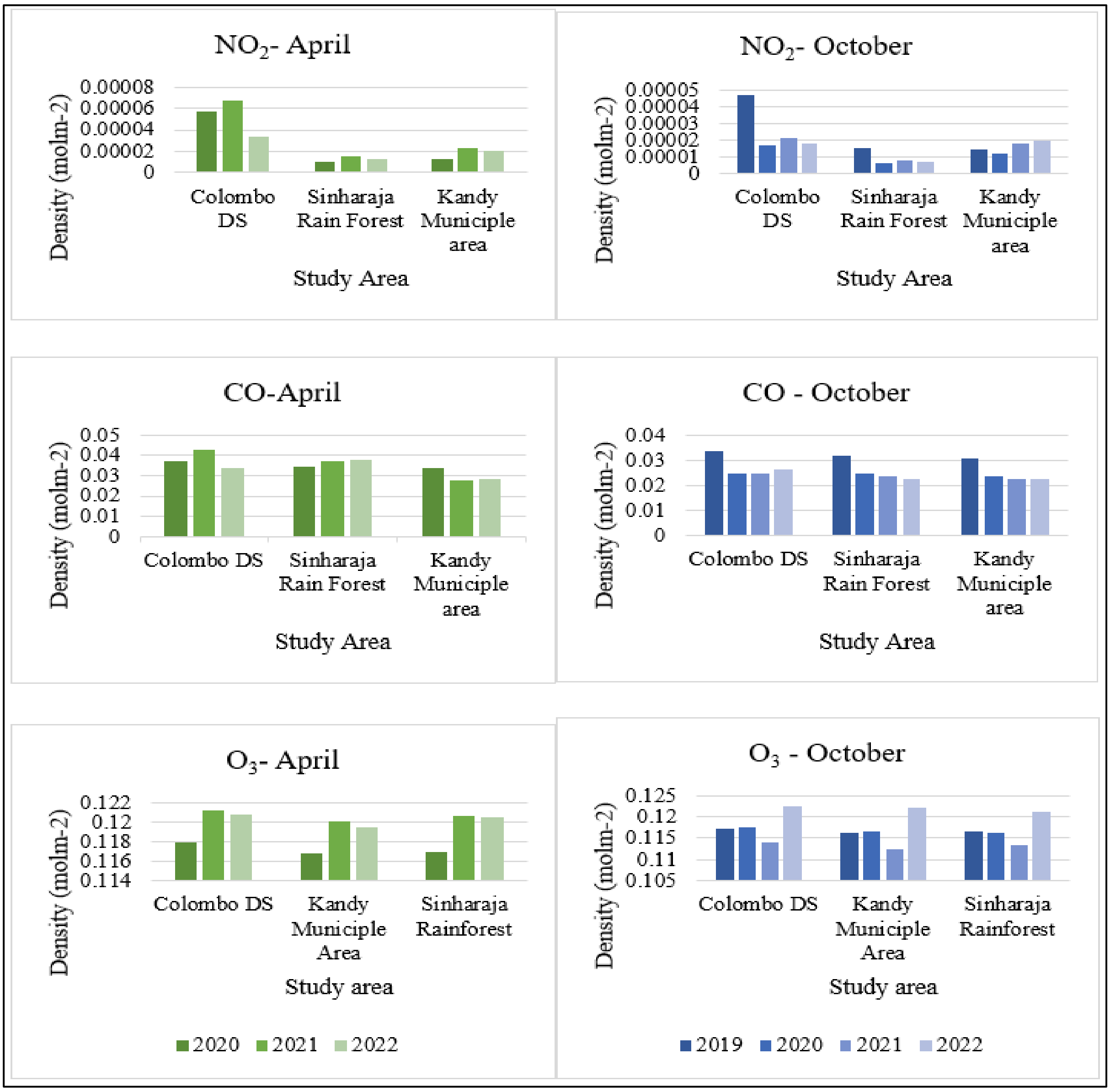

Figure 14: Relationship of each pollutant with specified months (April, October)

d. SENTINEL 5p Validation

To complete the validation, process the data from ground monitoring systems were used. Sri Lanka has major two air quality monitoring systems in Battaramulla and Kandy. Those monitoring centers collect only Nitrogen dioxide and Ozone amounts around the area.

- **Nitrogen Dioxide validation**

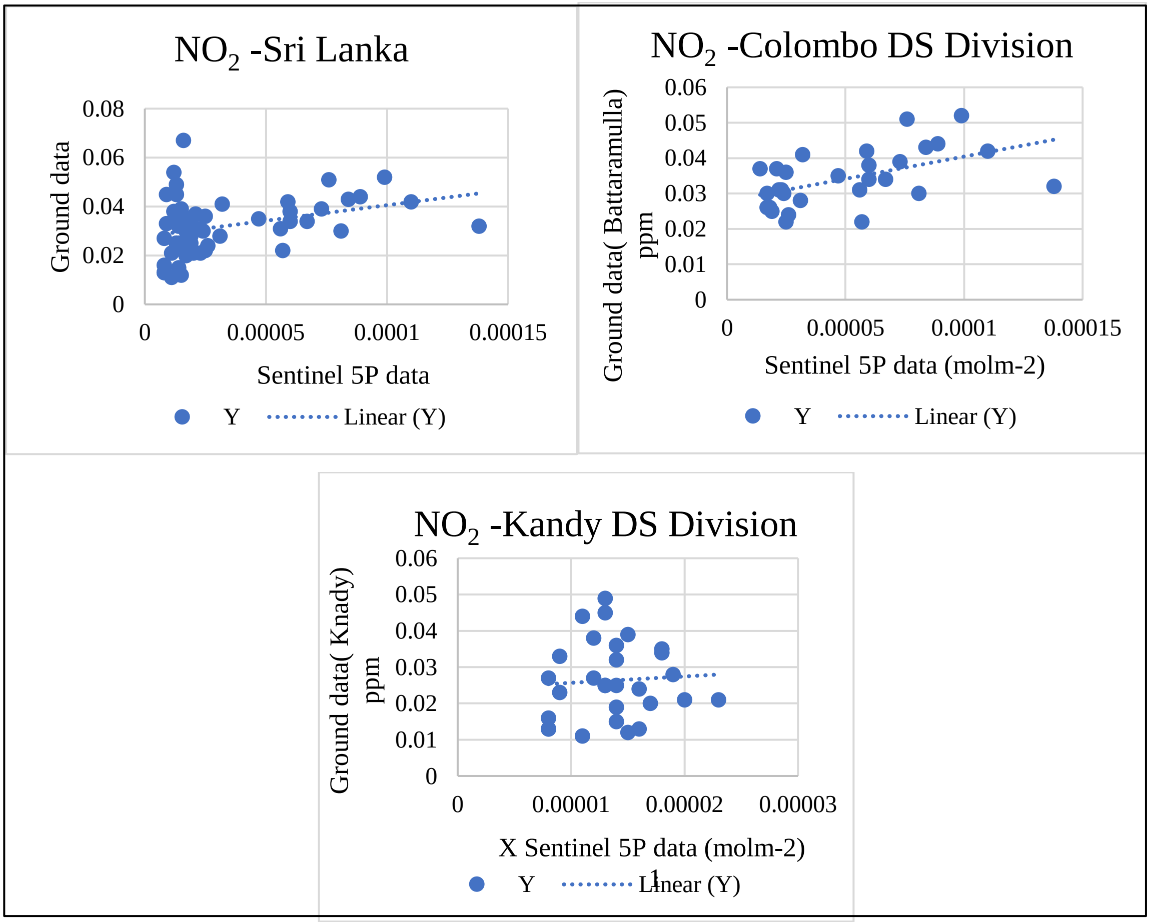

Figure 15 :Relationship between NO2 ground data and satellite data

Validation was done as three parts. First the validation was done for the Colombo Sub study area using Battaramulla monitoring station. Secondly validation was done for the Kandy area using Kandy ground monitored data. Then the validation done for the complete study area

The RMSE value for the ground and satellite NO_2 data is 0.5666 which is an average relationship between the two data sets.

- **Ozone validation**

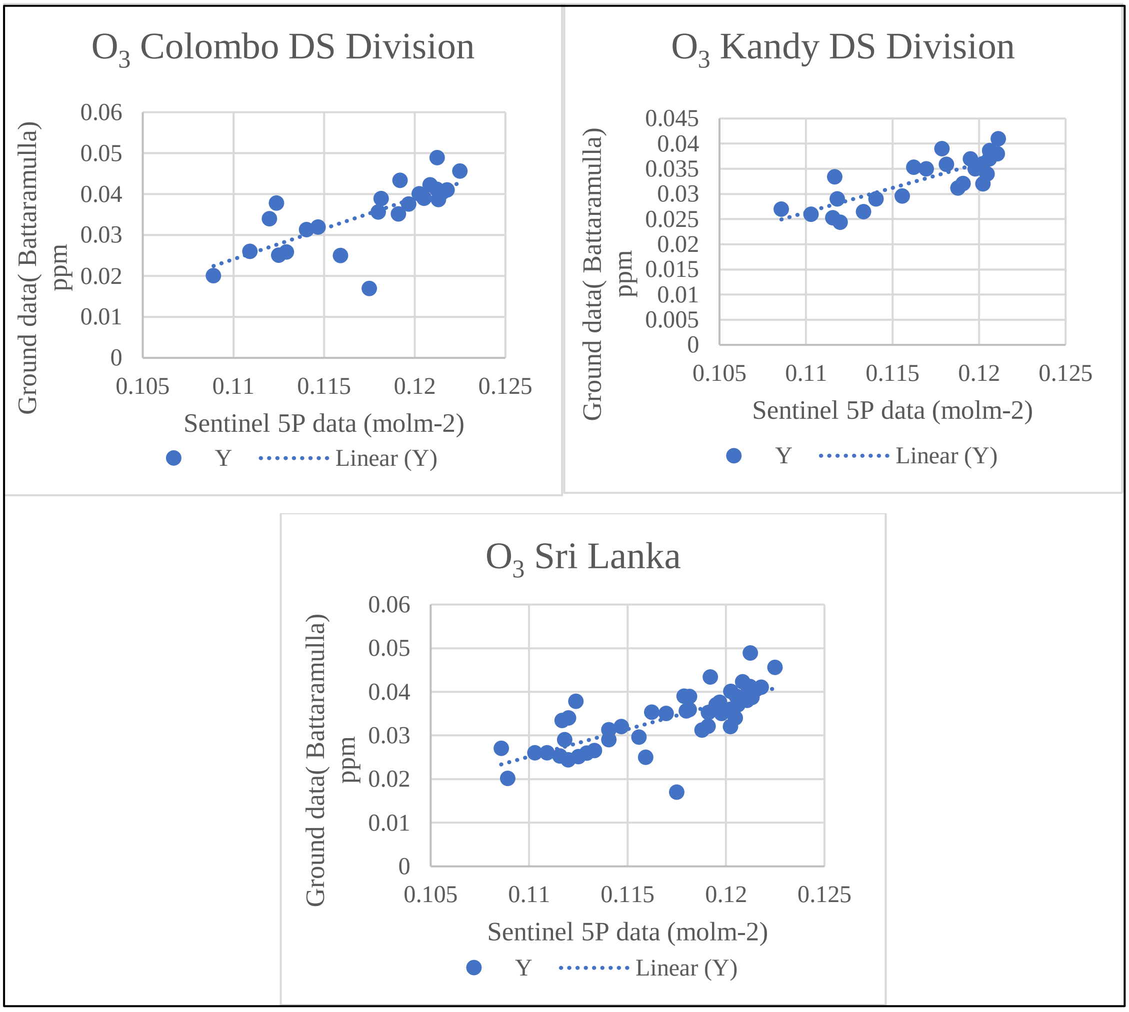

Figure 16 : Relationship between Ozone ground data and satellite data

Complete for Kandy and Colombo sub study areas and for the whole dataset. The RMSE values were 0.6556, 0.6043 and 0.5644. an average relationship of the data can be identified.

Conclusion and Recommendation

Reducing air pollution as a result of restricted human activity during the lockdown period offers a once-in-a-lifetime chance to study emission reductions and their effects on air quality. Therefore, in this study we examined the spatiotemporal characteristics of NO_2, O_3, SO_2, and CO in Six different sub areas including Colombo DS division, Biyagama DS division, Kandy municipal area, Sinha Raja Forest, Horton Plains in Sri Lanka, during normal and lockdown periods between 2019 and 2022.

The ESA Sentinel-5P satellite system provides high-resolution, free, and open data packages for monitoring air quality at several scales, from cities to global coverage. It gives continuous data on pollution distribution with daily global coverage. This information supplements the limited point information provided by ground-based stations. As demonstrated in the Bucharest case study, TROPOMI data from Sentinel-5P is useful for simulating unintentional pollutant discharges. However, limitations include the possibility of cloud interference and the restricted number of daily observations, which can make precise monitoring of contaminants that spread swiftly in the atmosphere difficult. Overall, Sentinel-5P improves air quality analysis, although its limitations must be recognized.

a. COVID lockdown effects on Air pollutants

The study found a significant connection between COVID lockout deployment and air pollutants, notably nitrogen dioxide (NO_2) and ozone (O_3). The study found a significant decrease in NO_2 and O_3 levels during the lockdown period, demonstrating a strong link between reduced human activity and improved air quality. The link between carbon monoxide (CO) and lockdown measures, on the other hand, was not statistically significant. Overall, the findings show that COVID lockdowns have a positive influence on NO_2 and O_3 emission reduction.

b. Reliability of the Sentinel 5P data set

The regression analysis indicates a strong relationship between ground data and pollutants such as NO_2, O_3, and CO. The lack of sufficient monitoring stations limits comprehensive data collection and prevents the establishment of reliable correlations. To overcome this, it is crucial to expand the network of ground monitoring stations for better coverage. Additionally, addressing the maintenance issues of databases is essential to ensure accurate and consistent data. Regular data collection at equal intervals is another important step to enhance accuracy. By improving monitoring networks, enhancing database conditions, and implementing consistent data collection practices, the accuracy and reliability of pollutant analysis can be significantly improved.

c. Factors effect for the Air pollutant variation

This research focuses on the examination of pollutants, specifically gases that display typical gas characteristics. The gases studied in this study are sensitive to temperature changes. The density of these gases reduces at high temperatures while increasing at low temperatures. The study uncovers a similar relationship for the pollutants NO_2 and CO. These two elements have the maximum density levels in December and January, which correspond to the coldest months. In contrast, as temperatures rise, especially in August, the density of these components falls.

In addition, ozone has a direct association with sunshine. On a global scale, the density of ozone drops as one gets closer to the equator and the sun. Furthermore, the density of ozone varies seasonally due to the Earth's inclination angle. This study also reveals significant annual fluctuations in ozone density.

d. Recommendation.

The resolution of the Sentinel 5P satellite images are 1132.2 meter. This is a massive resolution to analyses the atmospheric data relative to the spatial data. Therefore, as future development the resolution of the satellite images should have a smaller resolution. Data filtering process is need to do for all the data.

This model is much reliable for large areas which has a significant Air pollution due to industrial and traffic to identify the changers in the due to COVID pandemic lockdown.

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