

## **AIR QUALITY ANALYSIS OF CHITTAGONG, BANGLADESH USING GOOGLE EARTH ENGINE AND REMOTE SENSING: IMPLICATIONS FOR SUSTAINABLE URBAN DEVELOPMENT**

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### **ABSTRACT**

Nowadays, a significant portion of the global population lives in urban areas where air pollution levels are high. The primary objective is to utilize satellite data and the Google Earth Engine (GEE) platform to analyze the distribution of various air pollutants in Chittagong, Bangladesh. The study used Sentinel 5-P data sets for mapping carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), methane (CH<sub>4</sub>), formaldehyde (HCHO), ozone, and cloud cover in different seasons, such as winter, summer, and monsoon. Maps were prepared using ArcGIS 10.8. The concentration of carbon monoxide (CO) is between 0.031 and 0.049 mol/m<sup>2</sup>. The average concentration of sulfur dioxide (SO<sub>2</sub>) ranges between 0.0003-0.1317 mol/m<sup>2</sup>, whereas formaldehyde (HCHO) concentrations are within the range of 0.000028 to 0.00014 mol/m<sup>2</sup>. The study suggests that the increase of different air pollutants caused by various human activities, industrialization, e.t.c. By identifying the pollution hotspots and seasonal trends, this research gives necessary insights for policymakers to implement a sustainable environment.

**Keywords:** *Sustainability , Air Quality , Seasonal variation , Sentinel 5-P , Google Earth Engine*

## **1. INTRODUCTION**

Human activities such as burning of fossil fuels, industrialization, etc., lead to the accumulation of greenhouse gases such as carbon monoxide (CO) and formaldehyde (HCHO) in the Earth's atmosphere, which cause changes in the climate, global warming, and imbalance in the energy (Chu et al., 2010). Pollutants such as CO, NO<sub>2</sub>, SO<sub>2</sub>, CH<sub>4</sub>, and HCHO significantly affect air quality, human health, and sustainable development (Islam et al., 2021). An increase in the world temperature can cause extreme droughts, floods, storms, and wildfires that affect ecosystems and human life (Jodhani et al., 2023). Vehicular emissions and industrial activities are primarily responsible for the increase in the concentration of CO worldwide (Mampitiya et al., 2023; Ray et al., 2022). On the other hand, coal-based power plants have increased rapidly, which has boosted SO<sub>2</sub> releases, while NO<sub>2</sub> emissions through fossil fuel combustion have led to respiratory problems. The major portion of carbon monoxide comes from transportation and industrial sectors, which may cause intoxication and lower respiratory tract disorders, such as pain during inspiration. In rural areas, kerosene lamps contribute to air pollution by emitting high levels of PM<sub>2.5</sub> and black carbon (Lam et al., 2012). Other pollutants, such as burning, forest fires, agricultural chemicals, and dust, also contribute significantly to increased particulate matter in the atmosphere (Kinsey et al., 2005). In this research, Google Earth Engine (GEE) is used to compute the air pollution level across Chittagong city using Landsat and Sentinel-5P satellite data. Generally, Sentinel-5P is used for measuring air pollutants, while MODIS data is utilized to analyze the variation in Aerosol Optical Depth (Jodhani et al., 2024). Air pollution has become a significant issue in recent decades, particularly in developing nations like Bangladesh. Although some studies have been conducted on air quality in different cities of Bangladesh, the number of studies focusing on different cities of Bangladesh is not sufficient. Therefore, this study aims to calculate the concentration of different air pollutants in Chittagong city and draw attention to the relevant authority to detect pollution patterns as well as environmental impact evaluations for policy development (Choudhary et al., 2022). For example, shifting to electric vehicles offers a double win: improved fuel efficiency and reduced air pollution (Wu et al., 2017). Electrifying transportation reduces carbon emissions simultaneously (Zhao et al., 2021).

## **2. METHODOLOGY**

### **2.1 Study Area**

Geographically, Chittagong is situated between latitudes 22°14' N and 22°24' N and longitudes 91°46' E and 91°53' E (Huraira et al., 2025). The city is bordered to the north by the districts of Feni and Noakhali, to the south by Cox's Bazar, and to the east by the Chittagong Hill Tracts. The city comprises hills alongside rivers and coastal plains. Since the region has the main seaport of Bangladesh, our study area serves as the significant commercial capital of the country. Many industries, including production and processing facilities, have established themselves to support the city's commercial activities. Apart from industrialization, several development projects, such as road and bridge construction, supporting rapid urbanization, are also widespread here. These industries and development activities may significantly contribute to the emission of gases and dust that are responsible for air pollution, which needs to be investigated for the well-being of the residents, and also the co-existence of residential and industrial prospects. Despite Chattogram district being the second most vulnerable city to air pollution after Dhaka, there has not been a comprehensive trend analysis of pollutants in this area. Hence, our study aims to explore this regard and has selected the Chattogram district as our investigation region.

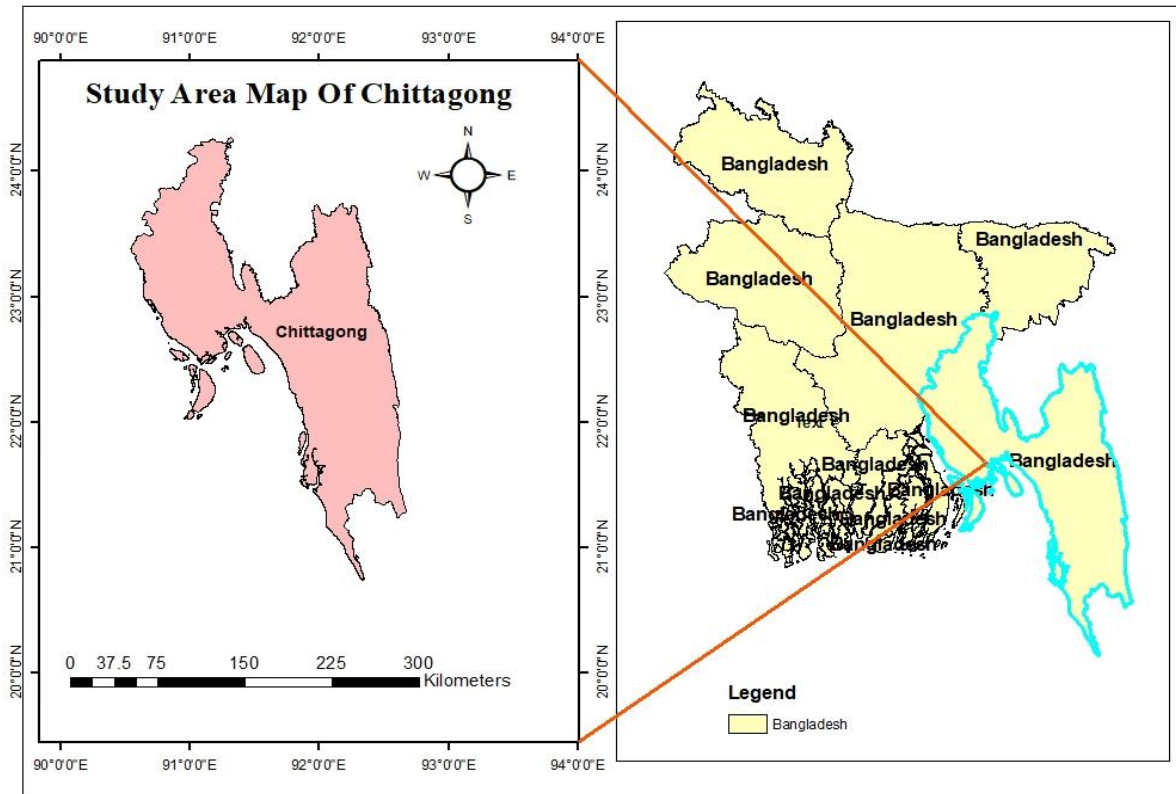


Figure 1: Study Area Map of Chittagong

### 2.1.1 Dataset Collection

Chittagong was selected as the study area due to its population of over 9 million and its status as a major industrial and commercial hub. Sentinel-5P satellite data were used to identify air pollutants such as CO, NO<sub>2</sub>, SO<sub>2</sub>, CH<sub>4</sub>, and HCHO, which cause a significant impact on human health. Google Earth Engine (GEE), was used for satellite data processing. JavaScripts were integrated within the GEE code editor for mapping pollutant concentrations over Chittagong city. The earth radiance measurements in different spectral regions provided vertically integrated column density values for CO, NO<sub>2</sub>, SO<sub>2</sub>, and HCHO in (mol/m<sup>2</sup>) and column volume mixing ratios for CH<sub>4</sub> in (ppb). Pollutant data were collected for three different seasons: winter (December 1, 2024, to January 30, 2025), summer (March 1, 2024, to May 31, 2024), and monsoon (August 1, 2024 to October 30, 2024). In the GEE software, the concentration of the pollutants in Chittagong city was collected using the inspector tool, which provides concentration data of pollutants in the region of interest. We used different Java scripts for mapping each pollutant in GEE by directly integrating the satellite data sets for the respective period based on the different seasons, and output in GEE generated in the form of a TIFF file format. The raster data were generated using GEE, and the raster data for all pollutants in different seasons were exported to ArcGIS software. The maps were prepared in ArcGIS 10.8 for each pollutant for different seasons and processed using raster data as an input file and different tools available within ArcGIS.

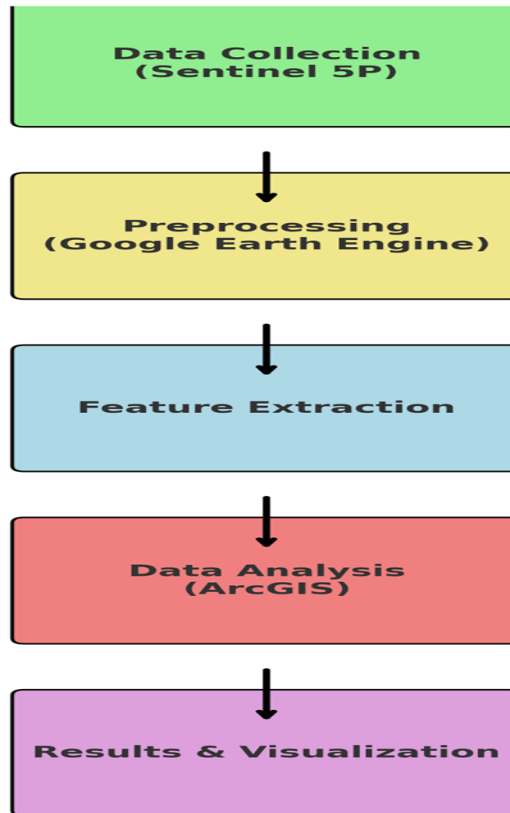


Figure 2: Methodology Flow Chart

### 2.1.2 Acquiring Normalized Difference Vegetation Index data using Google Earth Engine

Google Earth Engine (GEE) acts as an efficient platform for analyzing air quality data using satellites. The Sentinel-5P provides key datasets for monitoring atmospheric pollutants such as nitrogen dioxide (NO<sub>2</sub>), carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), ozone (O<sub>3</sub>), and particulate matter. These datasets are available in GEE and can be processed using its cloud computing capabilities. The COPERNICUS/S5P/NRTI/L3 collection provides daily global coverage of air pollutants. The key steps in acquiring air quality data are given below:

1. Defining the Region of Interest (ROI) – A specific geographic area is selected for analysis.
2. Filtering by Date – The dataset is constrained to the required time period.
3. Selecting Pollutants – Specific bands such as NO<sub>2</sub>\_column\_number\_density or CO\_column\_number\_density are chosen.
4. Applying Cloud Masking – Clouds and missing values are filtered out to improve data quality.
5. Aggregating Data – Mean pollutant values are calculated over the selected area for a specified period.

The following GEE script demonstrates how to acquire CO concentration data over a specified region:

```
// Define the region of interest (ROI)
var roi: Table projects/ee-mehedi1701050/assets/Chittagong

// Define time range
var startDate = '2024-01-01';
var endDate = '2025-01-31';

// Load Sentinel-5P CO dataset
var s5p = ee.ImageCollection('COPERNICUS/S5P/NRTI/L3_CO')
.filterBounds(roi)
.filterDate(startDate, endDate)
.select('CO_column_number_density');

// Function to extract mean CO concentration over ROI
var getCO = function(image) {
var meanCO = image.reduceRegion({
reducer: ee.Reducer.mean(),
geometry: roi,
scale: 1113, // Sentinel-5P resolution
bestEffort: true
}) get('CO_column_number_density');

return ee.Feature(null, {
'date': image.date() format('YYYY-MM-dd'),
'CO': meanCO
});
};

// Apply function to each image in the collection
var coTimeSeries = s5p.map(getCO).filter(ee.Filter.notNull(['CO']));

// Convert to chart
var chart = ui.Chart.feature.byFeature(coTimeSeries, 'date', 'CO')
.setChartType('ScatterChart')
.setOptions({
title: 'CO Concentration (Jan 2024 - Jan 2025)',
hAxis: {title: 'Date'},
vAxis: {title: 'CO (mol/m2)'},
pointSize: 3,
colors: ['blue']
});

// Print Chart
print(chart);
```

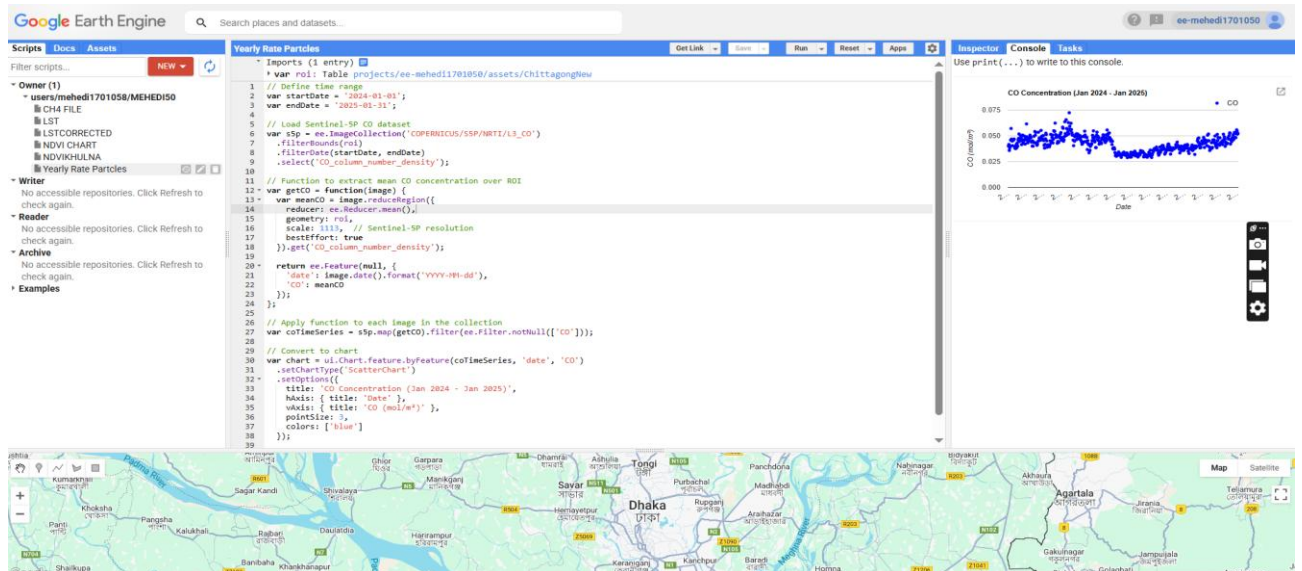


Figure 3: GEE Code Editor with executed script

### 3. FIGURES AND GRAPHS

The figure illustrates the spatial distribution of Nitrogen Dioxide ( $\text{NO}_2$ ) concentrations over Chittagong in three different seasons: summer (2024), monsoon (2024), and winter (2025). The data is derived from the Sentinel-5P satellite and analyzed using Google Earth Engine (GEE). During summer 2024, higher  $\text{NO}_2$  concentrations are observed in the central regions of Chittagong, particularly in densely populated and industrialized areas. The highest recorded value is **0.000149346 mol/m<sup>2</sup>**, while the lowest is **5.93718e-05 mol/m<sup>2</sup>**. In monsoon 2024,  $\text{NO}_2$  concentrations decrease significantly, with a maximum value of **8.96338e-05 mol/m<sup>2</sup>**, as rainfall helps remove pollutants from the atmosphere.

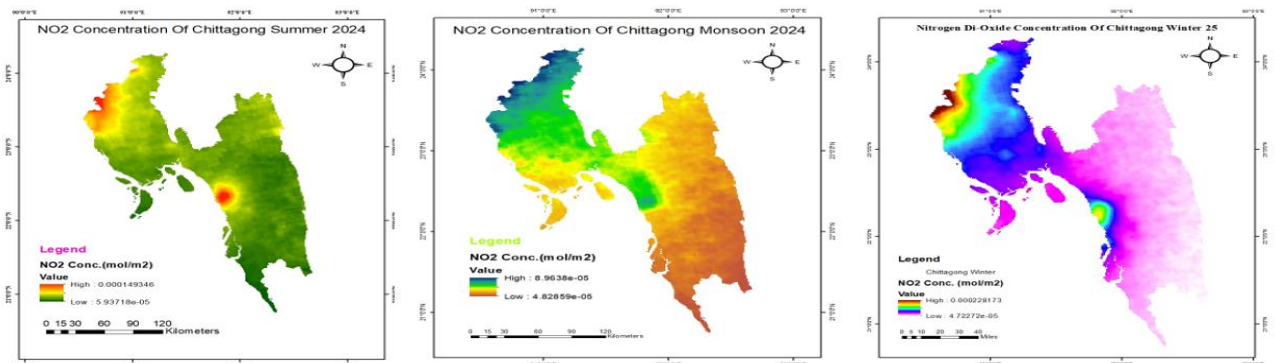


Figure 4: Concentration of Nitrogen Dioxide in various seasons in Chittagong (Summer 2024, Monsoon 2024, Winter 2024-25)

During winter 2025,  $\text{NO}_2$  levels peak at **0.00022173 mol/m<sup>2</sup>**, likely due to increase fuel combustion. These seasonal trends highlight the impact of weather on air pollution and emphasize the need for targeted mitigation strategies, particularly during winter.

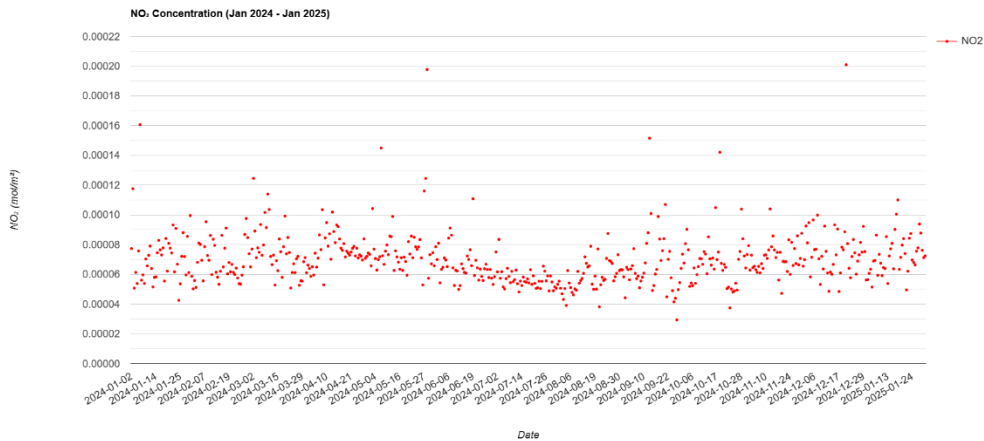


Figure 5: Time Series Chart of Nitrogen Dioxide in Chittagong from (Jan 2024-Jan 2025)

The figure presents a scatter plot of nitrogen dioxide ( $\text{NO}_2$ ) concentration over time from January 2024 to January 2025. From the chart, some noticeable upward trends in  $\text{NO}_2$  concentration occur around early January 2024, late May 2024, and August 2024, where the values exceed  $0.00016 \text{ mol/m}^2$ . In contrast, downward trends can be observed around June 2024 and September 2024, where  $\text{NO}_2$  concentration close to  $0.00004 \text{ mol/m}^2$ . The overall trend appears slightly downward, along with fluctuations across the year.

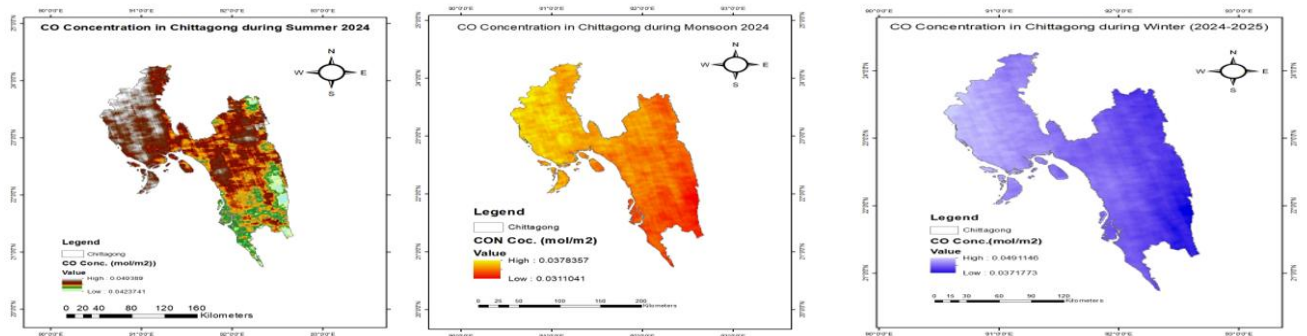


Figure 6: Concentration of Carbon Monoxide in various seasons in Chittagong (Summer 2024, Monsoon 2024, Winter 2024-2025)

The figure shows seasonal CO concentration in Chittagong for 2024–2025. In summer, CO levels are highest ( $0.042\text{--}0.054 \text{ mol/m}^2$ ), with pollution concentrated in central and northern areas. During monsoon, CO decreases to ( $0.031\text{--}0.037 \text{ mol/m}^2$ ) and is more evenly distributed. In winter, CO levels are lowest ( $0.037\text{--}0.049 \text{ mol/m}^2$ ), with a significant reduction across the region. This suggests atmospheric conditions and human activities have significant impact on seasonal variations.

On the other hand, **Fig. 7** illustrates the concentration of carbon monoxide (CO) from January 2024 to January 2025. The x-axis represents the dates, while the y-axis shows the CO concentration in  $\text{mol/m}^2$ . The concentration marked in blue, indicate fluctuations of CO levels over time. The trend

illustrates an initial increase, followed by a decline around mid-2024, and then a subsequent rise toward the end of the year.

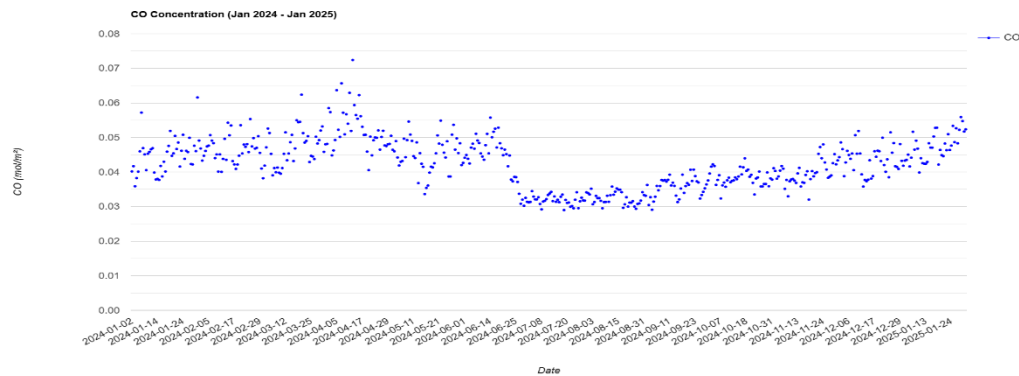


Figure 7: Time Series Chart of Carbon Monoxide in Chittagong from (Jan 2024-Jan 2025)

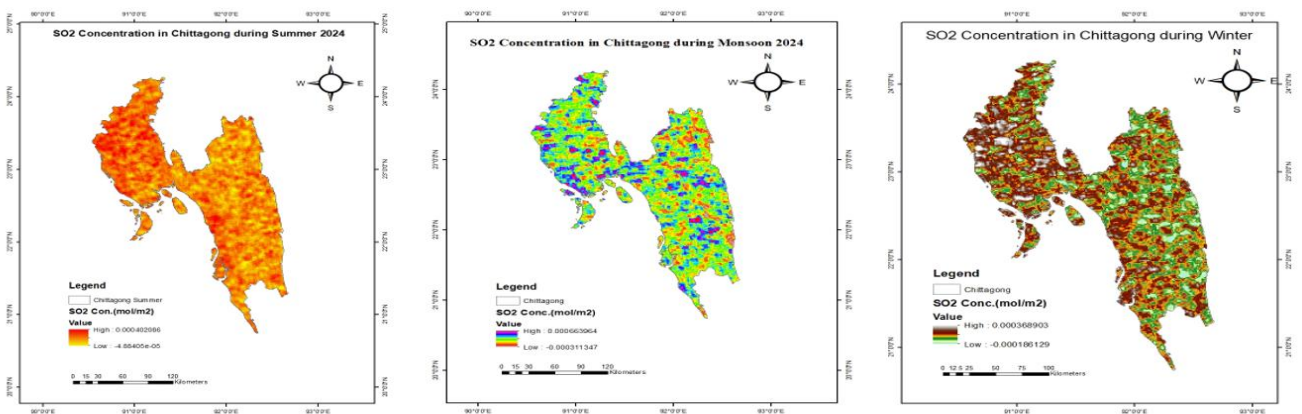


Figure 8: Concentration of Sulfur Dioxide in various seasons in Chittagong (Summer 2024, Monsoon 2024, Winter 2024-2025)

The figure represents the concentration of sulfur dioxide ( $\text{SO}_2$ ) in Chittagong during three different seasons in 2024 (summer, monsoon, and winter). The summer map shows relatively high and uniform  $\text{SO}_2$  levels, values range up to nearly  $0.000420286 \text{ mol/m}^2$ . The monsoon map exhibits the fluctuation of  $\text{SO}_2$  due to seasonal weather changes such as rainfall, with a peak concentration of around  $0.000659364 \text{ mol/m}^2$ . During the winter season, the concentration of  $\text{SO}_2$  reaching up to  $0.000368903 \text{ mol/m}^2$ .

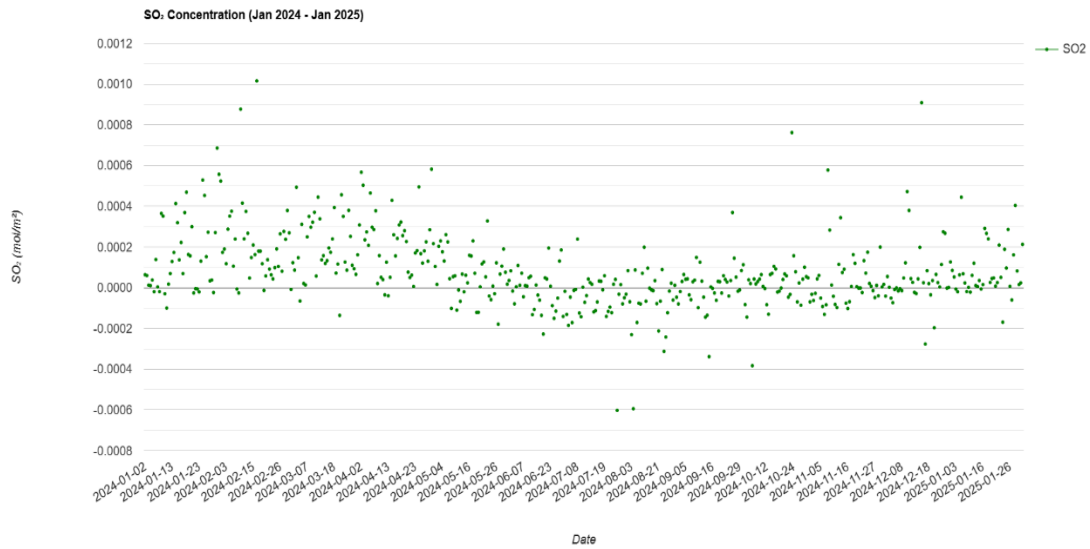


Figure 9: Time Series Chart of Sulfur Dioxide in Chittagong from (Jan 2024-Jan 2025)

Figure 9 shows the sulfur dioxide ( $\text{SO}_2$ ) concentration from January 2024 to January 2025, with the x-axis representing time and the y-axis indicating  $\text{SO}_2$  levels in  $\text{mol/m}^2$ . At the beginning of the year, the values generally remaining close to zero and occasional peaks and drops.

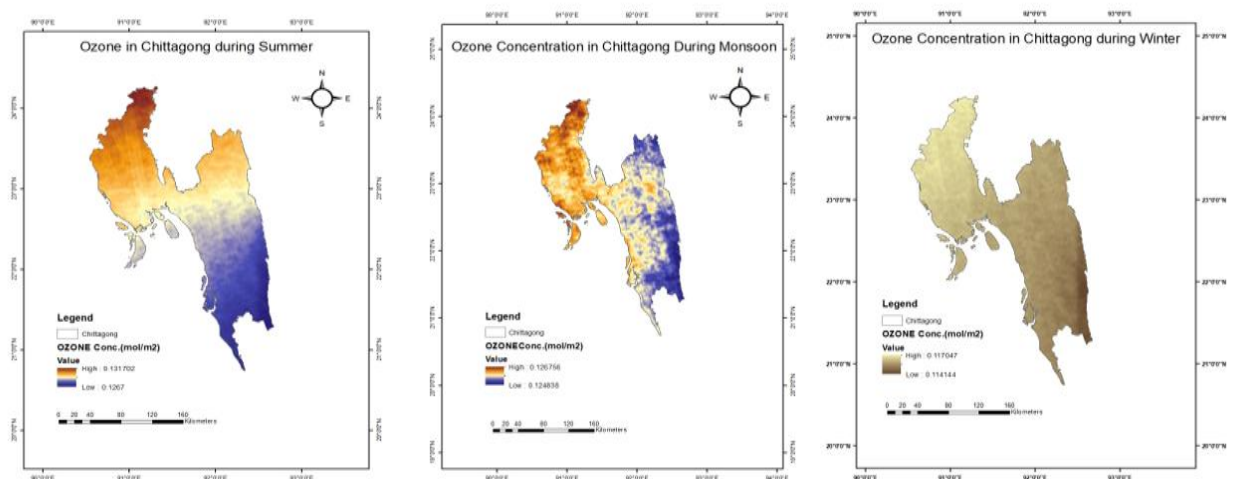


Figure 10: Concentration of Ozone in various seasons in Chittagong (Summer 2024, Monsoon 2024, Winter 2024-2025)

Figure 11 represents the temporal variation of ozone ( $\text{O}_3$ ) concentration (in  $\text{mol/m}^2$ ) from January 2024 to January 2025. The scatter plot displays an increasing trend from January to May, peaking around mid-year, followed by a gradual decline at the end of the year. This time series chart represents higher

ozone levels in summer and lower levels in winter, likely influenced by atmospheric conditions and photochemical reactions.

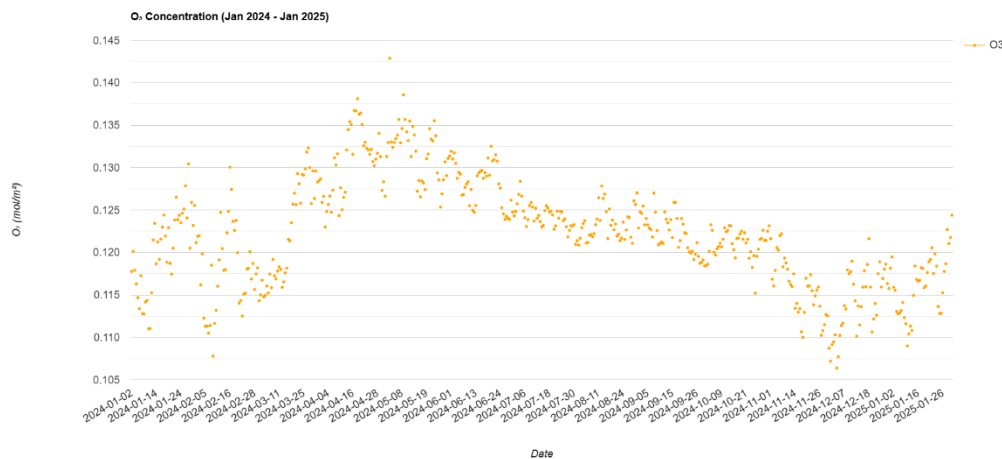


Figure 11: Time Series Chart of Ozone in Chittagong from (Jan 2024-Jan 2025)

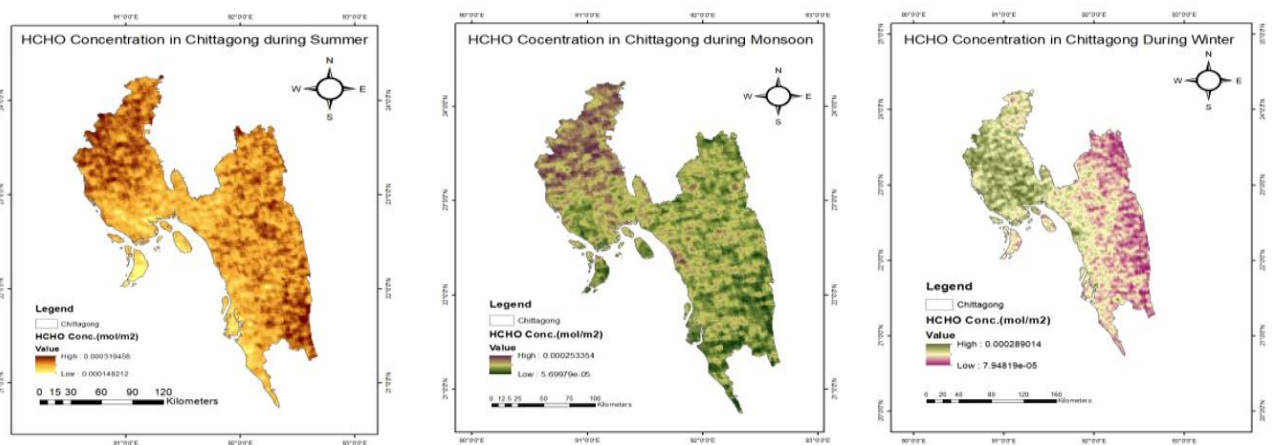


Figure 12: Concentration of Formaldehyde in various seasons in Chittagong (Summer 2024, Monsoon 2024, Winter 2024-2025)

The figure illustrates the spatial distribution of HCHO (formaldehyde) concentration in Chittagong, across three distinct seasons: Summer, Monsoon, and Winter. The Summer map, located on the left, shows the highest levels of HCHO concentration, with areas primarily shaded in orange to dark brown. In contrast, the Monsoon map in the middle reveals significantly lower concentrations. Lastly, the Winter map on the right shows moderate HCHO levels, with a mix of green and pink shades.

#### 4. CONCLUSION

This study analyzes the seasonal variations of different air pollutants such as CO, SO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, and HCHO over Chittagong city. Findings show that CO, SO<sub>2</sub>, and NO<sub>2</sub> peak in winter due to increased emissions, while during the monsoon rains reduced their levels. The research depicts the trend of pollutants in Chattogram and emphasizes the urgency of mitigating pollutant emissions as well as continuous monitoring of air quality in industrialized regions like Chattogram. During the dry period, public awareness should be more regarding air pollution. Coordinated approaches between the

government and private initiatives together can build a healthier and sustainable environment for future generations.

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## DECLARATIONS

The authors used an AI tool for describing GIS and Google Earth Engine (GEE) based figures. The AI tool was not used for data processing, analysis, or coding. All results are verified by the authors.

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