# Evaluation and Mapping the Atmospheric Air Quality of Coastal Area in Bangladesh Using Remote Sensing and GIS Techniques

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**ABSTRACT:** The coastal region of Bangladesh is increasingly suffering from air pollution in recent years. This study represents an analysis of the mean atmospheric column nitrogen dioxide ($NO_2$), Sulphur di oxide ($SO_2$), Ozone($O_3$), and carbon monoxide (CO) over the coastal area of Bangladesh during 2018-2022 period. Measurements of nitrogen dioxide ($NO_2$), Sulphur di oxide ($SO_2$), Ozone($O_3$) and carbon monoxide (CO) were obtained from recently launched Sentinel-5 Precursor spacecraft using Tropospheric Monitoring Instrument (Sentinel-5P TROPOMI). The aim of this study is to evaluate and visualize coastal air quality using relatively high-resolution data. $PM_{2.5}$ was analyzed for the period of 1998-2019 year and the data was collected from the SEDAC website. The $NO_2$, $SO_2$, $O_3$, $PM_{2.5,}$ and CO satellite data were then used in Google Earth Engine (GEE) and ArcGIS 10.7 software for further analysis and retrieval of the atmospheric data. The findings showed significantly high values for Khulna, Jashore, Satkhira, and Narail districts. From the $NO_2$ observation, high values were identified in Chandpur, Shariatpur, and Lakshmipur with a highest average value of 74.2 µmol/m$^2$. It was found that the $SO_2$ and $O_3$ were present significantly high over the Khulna, Bagerhat, Satkhira, and Narail districts. Particulate Matter $PM_{2.5}$ exceeded BNAAQS value in every year since 1998 all over the coastal Districts with an average value of 56 µg/m$^3$. Years 2020 and 2021 were found much clean air than the other study years might be due to the Covid-19 Lockdown all over the country. From the trend analysis, it was found that most of the air pollutants showed an increasing trend. The interior coast was found more polluted than the exposed coast. The overall results of this study confirmed the capability of Sentinel-5P TROPOMI data to be used in monitoring the air quality over coastal areas of Bangladesh. This study highlights the widespread problem of air pollution in the coastal districts of Bangladesh and emphasizes the need for immediate action to tackle this issue.

**Keywords:** Air Pollution; Coastal Region; Remote Sensing; Sentinels 5p TROPOMI

## INTRODUCTION

A significant global concern in recent years is air pollution, especially in light of the numerous negative effects it has on human health, the climate, the environment, culture, and customs, among other things. The level of air pollution in Bangladesh is increasing so sharply that it has been identified as a priority issue. Today, not only ecologists and scientists are concerned about it; the general public does as well. Urbanization, industrialization, energy use, transportation, and motorization are among the most significant contributor to air pollution in Bangladesh. The world's leading environmental health concern is air pollution, according to the World Health Organization (WHO) (WHO, 2016). Air pollution, along with climate change, is considered as a hazard to global health (Campbell and Prüss, 2019). However, the massive decline of air quality is caused by both man-made and natural processes. The main air pollutants we encounter every day include carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), ozone ($O_3$) and particulate matter (PM) (Chen et al., 2007). Near the Earth's surface, high levels of $O_3$, PM, and $NO_2$ can lead to major health issues such as respiratory and cardiovascular disorders (Dominici et al., 2010). Another source of air pollution is $NO_2$, which also acts as a preliminary to surface ozone, particulates, and acid rain (Bechle et al., 2013). The common contributors of $NO_2$ are the combustion of fossil fuels such as gas, oil, and coal. The functioning of vehicles, heating, coal power production, and biomass combustion all result in incomplete combustion, which produces CO (Godish et al., 2014). Around 40% of CO is produced by natural processes such as volcanic eruptions, gas emissions, the decline of plants and animals, and forest fires. The remaining 60% is generated through the use of fossil

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fuels, waste disposal, tobacco smoke, and charcoal fires (Varma et al., 2009). Recent investigations suggest a potential connection between urban Carbon monoxide concentrations and cardiac issues, despite the fact that tropospheric CO is not considered to be a health hazard outside (Andre et al., 2010).

Bangladesh's air quality has recently been a major source of worry due to severe overexposure to the limit values established to protect human health. Bangladesh's highest polluted city is Dhaka. In Dhaka, the degree of air pollution has continuously increased and reached a very harmful level (Motalib and Lasco, 2013). Motor vehicles and brick kilns seem to be the primary causes of particle air pollution in the city of Dhaka (Begum et al., 2011). However, air pollution has now spread all over Bangladesh including the coastal region. The coastal region of Bangladesh is a significant cultural and industrial center. Shipbreaking industries, tanneries, jute, textile, tea processing, petroleum refinery, paper, cement, fertilizer, pulp, food and pharmaceuticals, sugar, plastics, rubber, and brick manufacturing are common types of industries in and around the coastal area. The air in coastal areas is becoming increasingly polluted. Due to industrial pollutants, vehicle emissions, and extensive building, coastal districts are particularly susceptible to air pollution. Unplanned industry, brick kilns, automobile emissions, and other factors are significant sources of air pollution in Bangladesh's coastal regions. The lack of planning in industrial sector makes the issue more difficult. Large urban areas, like Dhaka, Khulna, and Chattogram, are more susceptible to air pollution.

There is a lack of studies on the distribution of air pollutants in the coastal region of Bangladesh. While AQI (Air Quality Index) is widely used to assess air quality in Dhaka, there is a scarcity of information on how air pollutants are distributed in the coastal region, which would provide a more comprehensive understanding of air quality in Bangladesh. Further research is needed in this area to fill this gap and gain insights into the air quality situation in the coastal region of Bangladesh. Therefore, this research evaluates the air quality of the coastal area in Bangladesh using remote sensing and GIS along with spatial distribution of air pollutants. The benefit of utilizing satellite image is that it can demonstrate the condition of the air across a wide region. This research summarizes several monitoring and analysis on ambient air quality levels of $NO_2$, $SO_2$, CO, $O_3$, and Particulate matters ($PM_{2.5}$) in Bangladesh's coastal regions. The coastal region of Bangladesh is an important area with a high population density and a significant contribution to the country's economy. The distribution of air pollutants in this region affects the health and well-being of the local population and the environment. A comprehensive understanding of the air quality in the coastal region can help identify sources of air pollution, guide policy-making for environmental protection, and improve public health. Utilizing remote sensing and GIS technology to evaluate air quality in this region can provide a more comprehensive and accurate assessment, which can support evidence-based decision-making and intervention. In summary, studying the air quality in the coastal region of Bangladesh is crucial for promoting sustainable development and improving the quality of life for the local population. The findings of this study will aid policymakers in developing national policies to combat air pollution by providing key insights into the importance of studying air quality in the region. This study can inform policy-making by highlighting the importance of addressing air pollution for promoting sustainable development and improving the quality of life for the local population. Based on this information, policymakers can develop and implement strategies to reduce air pollution in the coastal region, such as enforcing regulations, promoting clean technologies, and investing in renewable energy sources.

## METHODS OF THE STUDY

### Study Area

Geographically, the exposure of Bangladesh to climate change is particularly high because it is a low-lying riverine country (Qiu et al., 2021). In 2019, Bangladesh has the highest levels of air pollution, according to IQAir's global air quality assessment (Islam et al., 2020). The present study considered the whole coastal area of Bangladesh; an area of 46,271 $km^2$ is made up of 19 districts. This represents about 31% of the country's overall area where, a total of 12 coastal districts are categorized as the Exposed Coast and the remainder 7 coastal districts are referred to as Interior Coast (Uddin and Kaudstaal, 2003; Parvin et al., 2010). The exposed coast is limited to a range of 37 to 57 km, whereas the coastal zone extends from the beach of an area of 37 to 195 km.

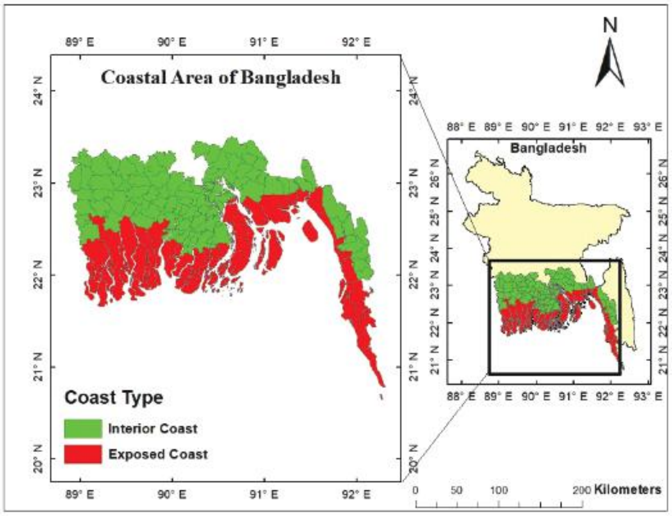


**Figure 1:** Location of the Expsed and Interior Coastal Areas in Bangladesh Selected for the Present Study

The districts of the exposed coast studied in this research were Chattogram, Cox's Bazar, Feni, Lakshmipur, Barguna, Bhola, Patuakhali, Pirojpur, Noakhali, Bagerhat, Khulna, and Satkhira, and districts of the interior coast studied in this research were Barisal, Jhalakathi, Chandpur, Gopalganj, Shariatpur, Jashore, and Narail. To assess the spatial distribution, $NO_2$, $SO_2$, CO, $O_3$ data were collected from 2018 to June, 2022, and PM2.5 data was collected from 1998 to 2019.

## Data Acquisition and Processing

Sentinel-5P satellite image was used in this research to assess air pollution in Bangladesh's coastal regions since they were accessible online. The Sentinel-5 Precursor was developed to provide data and services on the ozone layer, climate, and air quality. A component of Sentinel-5P is the TROPOspheric Monitoring Instrument (TROPOMI) (Vîrghileanu et al., 2020). Sentinel-5P's TROPOMI sensor is used in one of its missions to monitor gases in the atmosphere, such as $NO_2$, CO, $SO_2$, Ozone ($O_3$), formaldehyde ($CH_2O$), $CH_4$, and aerosol (Loyola et al., 2018). A passive-sensing hyperspectral imager called TROPOMI enables the acquisition of 8-band images that span the Ultraviolet, visible to NIR, and shortwave IR spectrums (Vîrghileanu et al., 2020). The spatial resolution (Table 1) of TROPOMI is 7 X 3.5 $km^2$, which is greater than all of its early pioneers. Sentinel-5P's excellent spatial resolution enables opportunities for identifying the causes of air pollution (Vîrghileanu et al., 2020).

**Table 1:** Sentinel-5P Tropomi L2 Image Data with Their Resolution, Bandwidth and Sensing Mechanisms

| Sl No | Parameter | Resolution | Band Width | Sensing Mechanisms |
|---|---|---|---|---|
| 1. | $NO_2$ | 7.0 km X 3.5 km | 270–495 nm | UV backscatter |
| 2. | $SO_2$ | 7.0 km X 3.5 km | 310–405 nm | UV wave-length Pairs |
| 4. | CO | 7.0 km X 7.0 km | 230 5nm- 2385 nm | Radiance (SWIR) |
| 5. | $O_3$ | 5.5 km X 3.5 km | 305–400 nm | Radiance (SWIR) |

This study used Sentinel-5P TROPOMI data to calculate the column number density of four pollutants: Sulfur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Carbon Monoxide (CO), and Ozone ($O_3$). Because these chemical species are present in all significant emission sources in some capacity, the selected pollutants are sufficient for describing the characteristics of air quality in Bangladesh's coastal area. As previously noted, Sentinel-5P TROPOMI products were used to analyze the patterns of $NO_2$, $SO_2$, CO and $O_3$ dispersion over the time frame indicated before. Because the primary mission focuses on analyzing the air quality in Bangladesh's coastal region and the total period spans more than five years, a huge volume of data needed to be processed. In this case, the Google Earth Engine is one of the best tools for analysis. For processing and interpretation, Google Earth Engine (GEE) was applied. In order to efficiently and affordably categorize and analyze a range of Earth observation data, Google established the Google Earth Engine (GEE) in 2010 (Gorelick et al., 2017; Kumar and Mutanga, 2018; Amani et al., 2020). When processing massive amounts of open-access Earth observation data over a wide area and for an extended period of time, this platform is invaluable (Hui et al., 2008; Amani et al., 2020). It allows for the rapid processing of data over a relatively long period of time over Bangladesh's coastal area. Because data for all selected pollutants is available in

Google Earth Engine. The total research period was five years for Sulfur Dioxide ($SO_2$), Nitrogen Dioxide ($NO_2$), Carbon Monoxide (CO) and Ozone ($O_3$) which was between 2018 – June 2022. And $PM_{2.5}$ observation data for 1998-2019 were collected from the SEDAC website and then analyzed in the Google Earth Engine (GEE). We divided the data into two seasons: dry season (December-January-February) and wet season (June-July-August). ArcGIS software was used for overall visualization and mapping the spatial and temporal distribution of air pollution. The chosen period allowed for an examination of the ongoing air pollution situation in Bangladesh's coastal areas, as well as the detection of key seasonal changes.

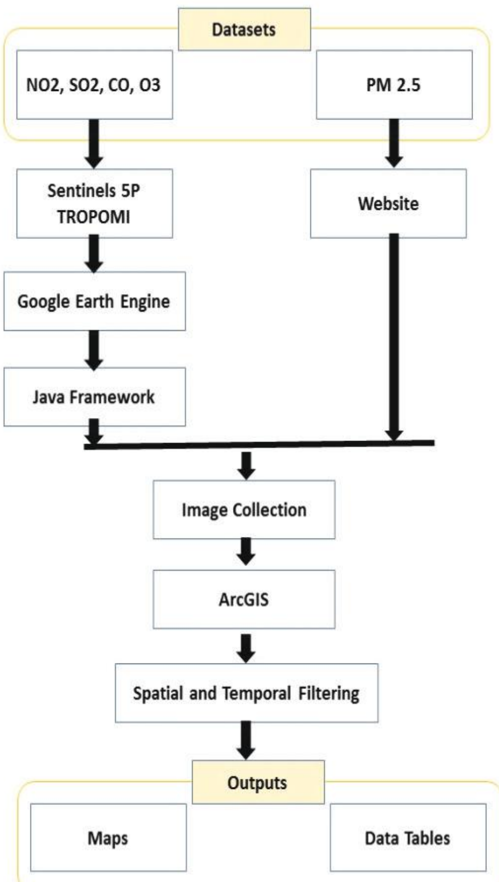


**Figure 2:** Flow Chart of Methods Applied

**Mann-Kendall Trend Analysis**

To identify trends in time series data, Mann-Kendall trend analysis was applied. It is often used to analyze weather and water-flow trends. This is a statistical method, which is extensively applied for trend analysis of meteorological time series data (Yue and Pilon, 2004; Liang et al., 2010; Zarenistanak et al., 2014). The Mann-Kendall (MK) trend analysis is a test for randomness against time, was developed by Mann (Mann, 1945) as a modification of Kendall's (Kendall, 1975) correlations approach. The MK test was used to compare each value in the data set to the remainder values in a sequential direction. The number of occasions the remaining elements are bigger than that under consideration is counted.

The following equation provides the Mann-Kendall statistic:

$$\mathbf{S} = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \mathbf{sign}(x_i - x_j)$$

Where, $x_i$, $x_j$ are data values and $n$ is the extent of the data collection.

The following values are assumed by the function:

$$\mathbf{Sign}(X_i - X_j) = \begin{cases} +1; \mathbf{if}(X_i - X_j) > 0 \\ 0; \mathbf{if}(X_i - X_j) = 0 \\ -1; \mathbf{if}(X_i - X_j) < 0 \end{cases}$$

When, n≥8, it is assumed that the variables are independent in nature and randomly distributed, and the statistic *S* has a roughly normal distribution with zero mean and the variance *Var (S)* as follows:

$$\mathbf{Var(S)} = \frac{1}{18}[n(n-1)(2n+5)]$$

Here, *Var(S)* is the variance of the Mann–Kendall statistic of the times-series and *n* is the length of the times-series.

The statistic for standardized testing is provided by:

$$\mathbf{Z} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \mathbf{if}\ S > 0 \\ 0, \mathbf{if}\ S = 0 \\ \frac{S-1}{\sqrt{Var(S)}}, \mathbf{if}\ S < 0 \end{cases}$$

To identify the existence of statistically significant trend, the Z value is used. This statistic was used to test null hypothesis in which there is no trend exists. A positive Z in the time series represents a rising trend, whereas a decreasing trend indicates a negative Z value.

## RESULTS OF THE STUDY

### Seasonal Variation

Four air pollutants from the research area, $NO_2$, $SO_2$, CO, and $O_3$, are shown in Figures 3 and 4 as seasonal variations. Wet season (June, July and August) and dry season (December, January and February) were analyzed in the present study. Because the satellite data for $PM_{2.5}$ was retrieved as an annual average, seasonal fluctuation of $PM_{2.5}$ was not analyzed.

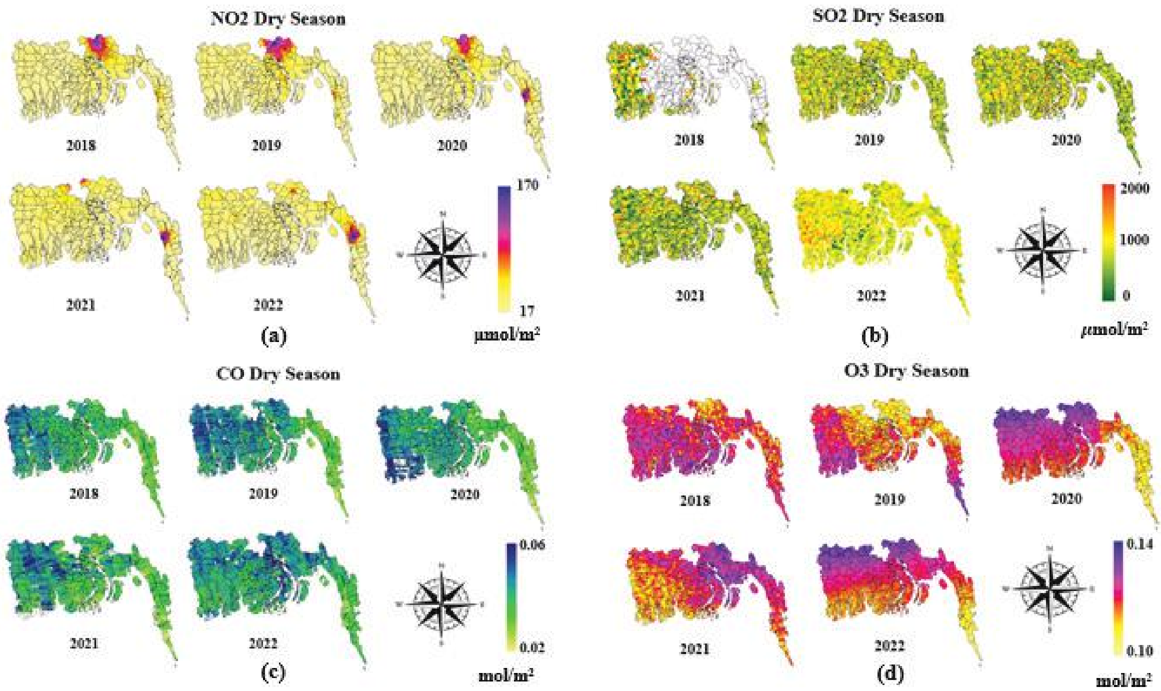


**Figure 3:** Spatial Distribution of (a) $NO_2$, (b) $SO_2$, (c) CO, and (d) $O_3$ in Dry Season

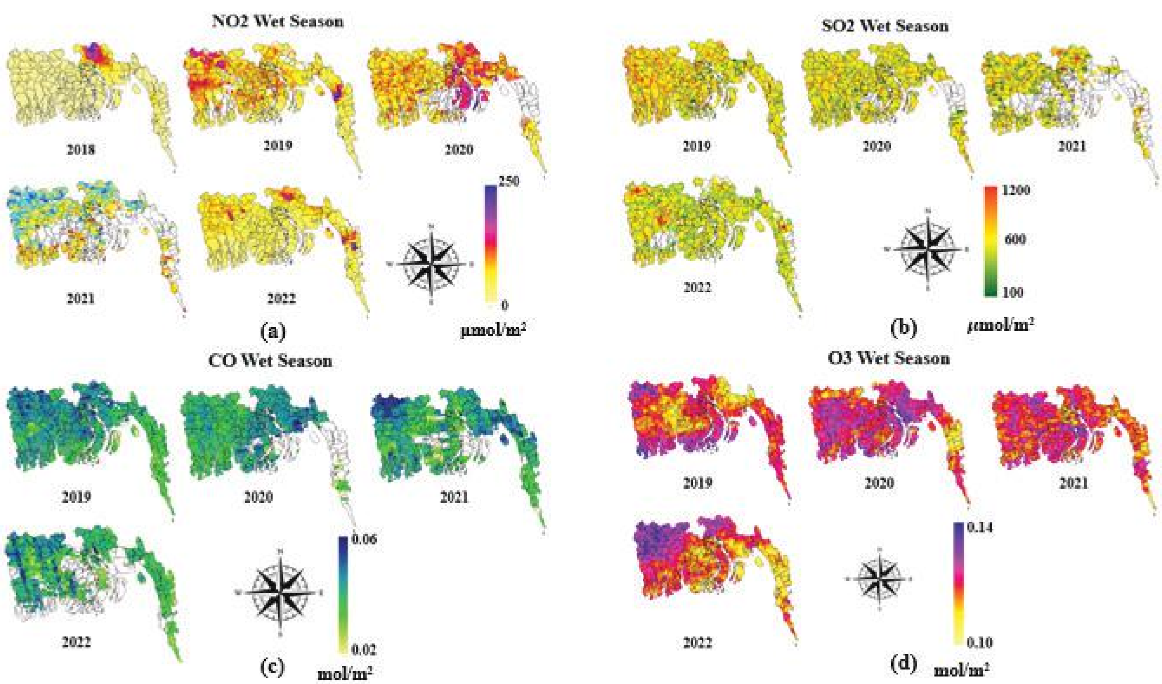


**Figure 4:** Spatial Distribution of (a) $NO_2$, (b) $SO_2$, (c) CO, and (d) $O_3$ in Wet Season

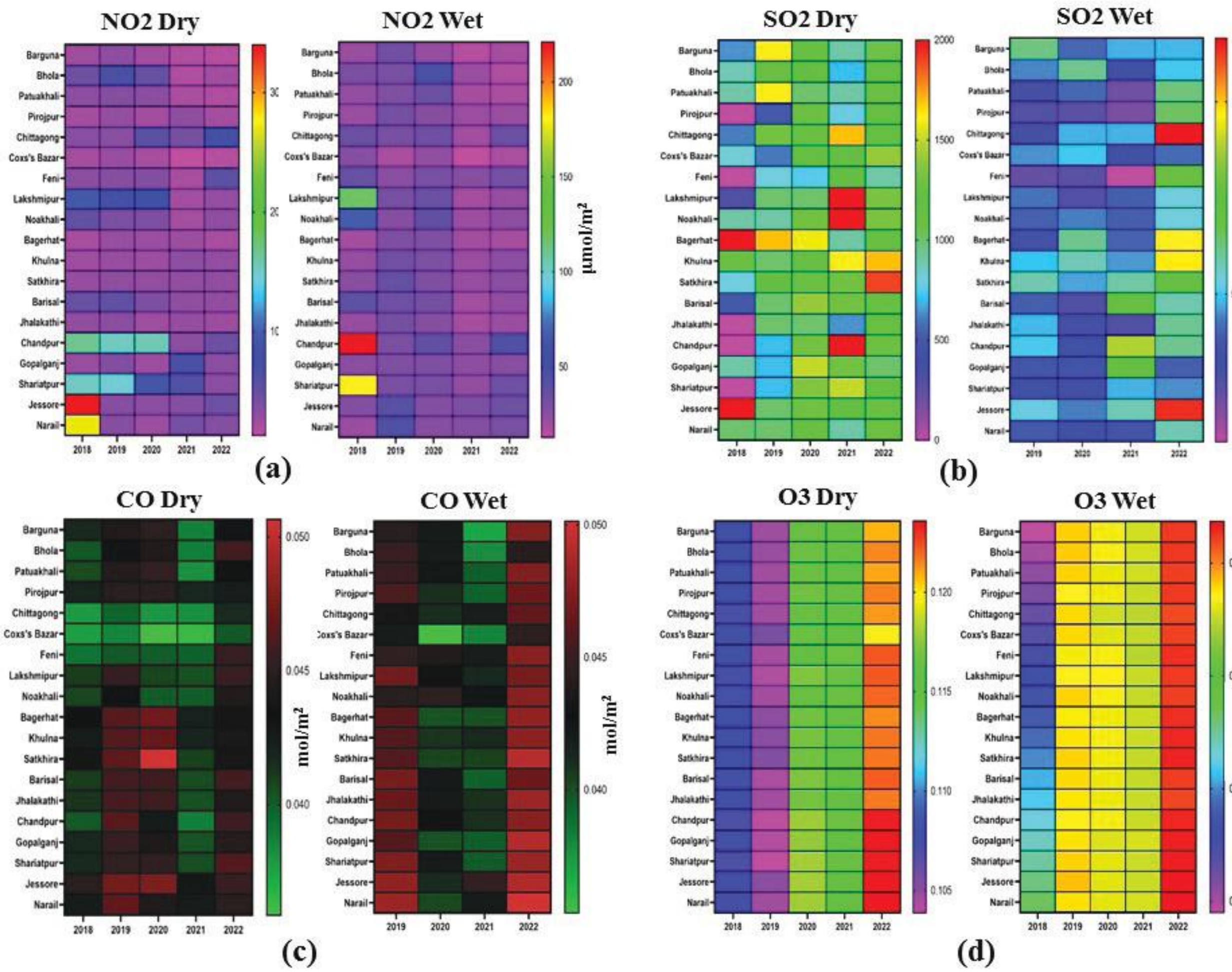


**Figure 5:** The Seasonal Heat Map Analysis of (a) $NO_2$, (b) $SO_2$, (c) CO, and (d) $O_3$

## Seasonal Variation of $NO_2$

The highest $NO_2$ column number density was observed over Chandpur, Shariatpur, and Lakshmipur. Average $NO_2$ column number density over mentioned cities exceed 74.2 µmol/m$^2$. Highest $NO_2$ content was recorded on 2018 wet season (June-July-August) in Chandpur which was 221 µmol/m$^2$. Average $NO_2$ content of Chandpur was 110.4 µmol/m$^2$ which was the highest among the other 18 districts. So, the highest amount of $NO_2$ content was found in Chandpur-Shariatpur-Lakshmipur region. The rest territory was rather clean with background $NO_2$ column number density of about 25 µmol/m$^2$. Minimal $NO_2$ concentrations are observed over Cox's Bazar, Patuakhali, Pirojpur, Jashore, and Narail region, where average values usually did not exceed 20 µmol/m$^2$ (Fig. 3 and 4).

Average $NO_2$ content was higher in 2018. In 2018, average $NO_2$ content in wet season was found 52.15 µmol/m$^2$ which was higher than the dry season which was 48 µmol/m$^2$. So, the highest amount of $NO_2$ content was found in 2018 wet season and lowest amount of $NO_2$ was found in 2021 wet season which was 21 µmol/m$^2$. Average lowest amount of $NO_2$ content was found in 2021 dry and wet season. So, the year 2021 was much cleaner than the other years because in 2021, Bangladesh went to the COVID-19 lockdown all over the country. Most polluted year was 2018. This was to be mentioned that, Wet Season was much Cleaner than the dry season. And 2021 was the cleanest year and 2018 was the most polluted year in the Coastal area of Bangladesh according to $NO_2$ content (Fig. 5).

### Seasonal Variation of $SO_2$

The regional distribution of tropospheric $SO_2$ over Bangladesh's coastal area from 2018 to June 2022 are shown in Figures 3 (b) and 4 (b). It was found that the most $SO_2$ pollution occurs in Bagerhat (1481 μmol/m²), Jashore (1318 μmol/m²), Noakhali (1283 μmol/m²), Chattogram (1183 μmol/m²) and their surrounding districts, such as Satkhira (1250 μmol/m²), Khulna (1310 μmol/m²). The majority of industries are clustered in these areas, which may contribute to air pollution. Furthermore, because of the presence of an industrial region, Chattogram and Khulna districts experienced $SO_2$ pollution. A comparison of maps made from the Sentinel-5P product's yearly average mosaic for tropospheric $SO_2$ concentrations revealed different trends in every year since the lockdown began. In wet season, 2020, when Bangladesh's government declared the first lockdown, in comparison to the same time period in 2019, the density of $SO_2$ in Bangladesh's coastal cities decreased dramatically. However, in 2021, there was no lockdown in dry season (January-February), as expected, the amount of $SO_2$ was found to be highest throughout the coastal area. The $SO_2$ content was greater than in the same period in 2019 (Fig. 3 and 4).

The government extended the lockdown during the wet season of 2020, and as a result, it is seen that the $SO_2$ concentration was significantly decreased. In comparison to the same time period in 2019, the concentration of $SO_2$ decreased significantly all across country, even in coastal cities. From the seasonal Average, it is observed that, the wet season was much cleaner than the dry season. The lowest $SO_2$ content was recorded in wet season 2020 which was 403 μmol/m². But the $SO_2$ content was increased in 2022 both dry and wet season. Because in 2022, no lockdown was implemented and every industrial process was running all over the coastal area. And this pollution was much higher in the dry season of 2022 which was 1242 μmol/m² The study also found that, Chattogram was the most $SO_2$ polluted city in the coastal area, having highest amount of $SO_2$ content in both seasons all over the time series (Fig. 5).

## Seasonal Variation of CO

From 2018 to June 2022, Figure 3(c) and 4(c) represents the regional distribution of tropospheric CO of Bangladesh's Coastal Area. The highest CO column number density was observed over Khulna, Jashore, Satkhira, and Narail. Average CO column number density over mentioned cities exceed 0.045 mol/m². Highest CO content was recorded on 2022 wet season (June) in Narail district which was 0.050 mol/m². Average CO content of Narail was 0.0461 mol/m² which is the highest among the other 18 districts. So, the highest amount of CO content was found in Khulna-Jashore-Narail region. The rest territory was also polluted with background CO column number density of about 0.044 mol/m². Minimal CO concentrations observed over Chattogram and Cox's region, where average values usually did not exceed 0.038 mol/m² (Fig. 3 and 4).

Average CO content was higher in 2022. In 2022, average CO content in wet season was found 0.0478 mol/m² which was higher than the dry season which was 0.044 mol/m². So, the highest amount of CO content was found in 2022 wet season and lowest amount of CO was found in 2021 dry which was 0.040 mol/m². Average lowest amount of CO content was found in 2021 dry and wet season. Hence, the year 2021 was much cleaner than the other years because in 2021, Bangladesh went to the COVID-19 Lockdown all over the country. Most polluted year is 2022. Wet season was more polluted than the dry season and 2021 was the cleaner year. However, 2022 was the most polluted year in the Coastal area of Bangladesh according to CO content (Fig. 5).

## Seasonal Variation of $O_3$

From 2018 to June 2022, Figure 3(d) and 4(d) depicts the regional distribution of tropospheric $O_3$ of Bangladesh's Coastal Area. The highest $O_3$ column number density was observed over Khulna, Jashore, Satkhira, and Narail. Average $O_3$ column number density over mentioned cities exceed 0.113 mol/m². Highest $O_3$ content was recorded on 2022 wet season (June) in Jashore district which was 0.1136 mol/m². Average $O_3$ content of Jashore was 0.1134 mol/m² which was the highest among the other 18 districts. So, the highest amount of $O_3$ content was found in Khulna-Jashore-Narail region. But $O_3$ was found in significant amount in all over the coastal area of Bangladesh (Fig. 3 and 4).

The rest territory was also polluted with background $O_3$ column number density of about 0.113 mol/m². Minimal $O_3$ concentrations observed over Chattogram and Cox's region, where average values usually do not exceed 0.112 mol/m². Average $O_3$ content was higher in 2022. In 2022, average $O_3$ content in wet season was found 0.1332 mol/m² which was higher than the dry season which is 0.122 mol/m². The highest amount of $O_3$ content was found in 2022 wet season and lowest amount of $O_3$ was found in 2018 dry which was 0.107 mol/m². Average lowest amount of $O_3$ content was found in 2018 dry and wet season. The year 2018 was much cleaner than the other years. Wet Season was cleaner than the Dry season. And 2018 was the cleaner year and 2022 was the most polluted year in the Coastal area of Bangladesh according to $O_3$ content (Fig. 5).

## Spatial Distribution of $PM_{2.5}$

In this analysis, Jashore district was found as the most polluted site being monitored under the study. Annual $PM_{2.5}$ concentrations in Jashore was observed about 67.66 µg $m^{-3}$ which indicated presence of robust sources of coarse particles ($PM_{2.5}$) around the district. High PM concentrations in Jashore region were experienced during when fine particles share the most of the $PM_{2.5}$ concentrations. Adjacent cities of the Jashore also showed similar kind of pollution level. Narail (67.4 µg $m^{-3}$), Shariatpur (65.4 µg $m^{-3}$), Gopalganj (67.2 µg $m^{-3}$), and Khulna (61.4 µg $m^{-3}$) hadthe highest average concentration value among the coastal areas of Bangladesh. Cox's Bazar was cleaner than the other district's $PM_{2.5}$ content which was 34.13 µg $m^{-3}$ (Fig. 7). From the analysis of heat map, it was found that from 2009 the concentration of $PM_{2.5}$ was increasing significantly. In 2012, Concentration of $PM_{2.5}$ was found high in Gopalganj, Shariatpur, Jashore and Narail (Fig. 6).

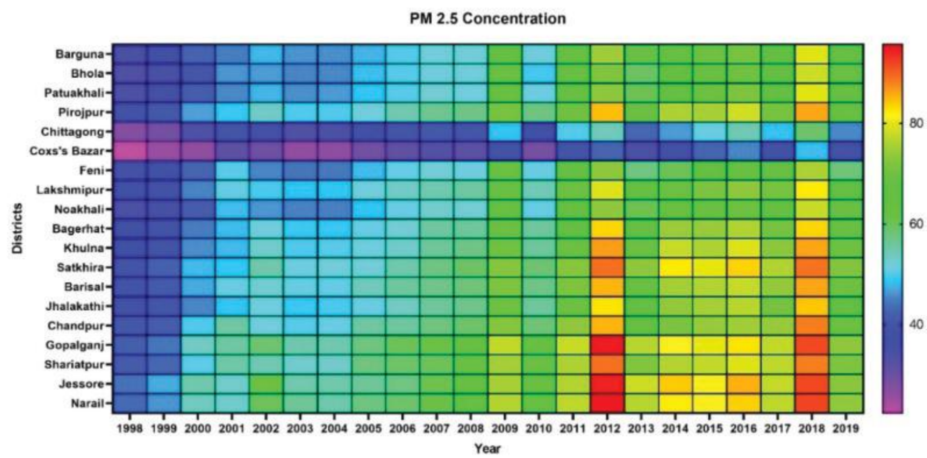


**Figure 6:** The Heat Map of $PM_{2.5}$ Concentration Observed from 1998 to 2019 in the Coastal Area of Bangladesh

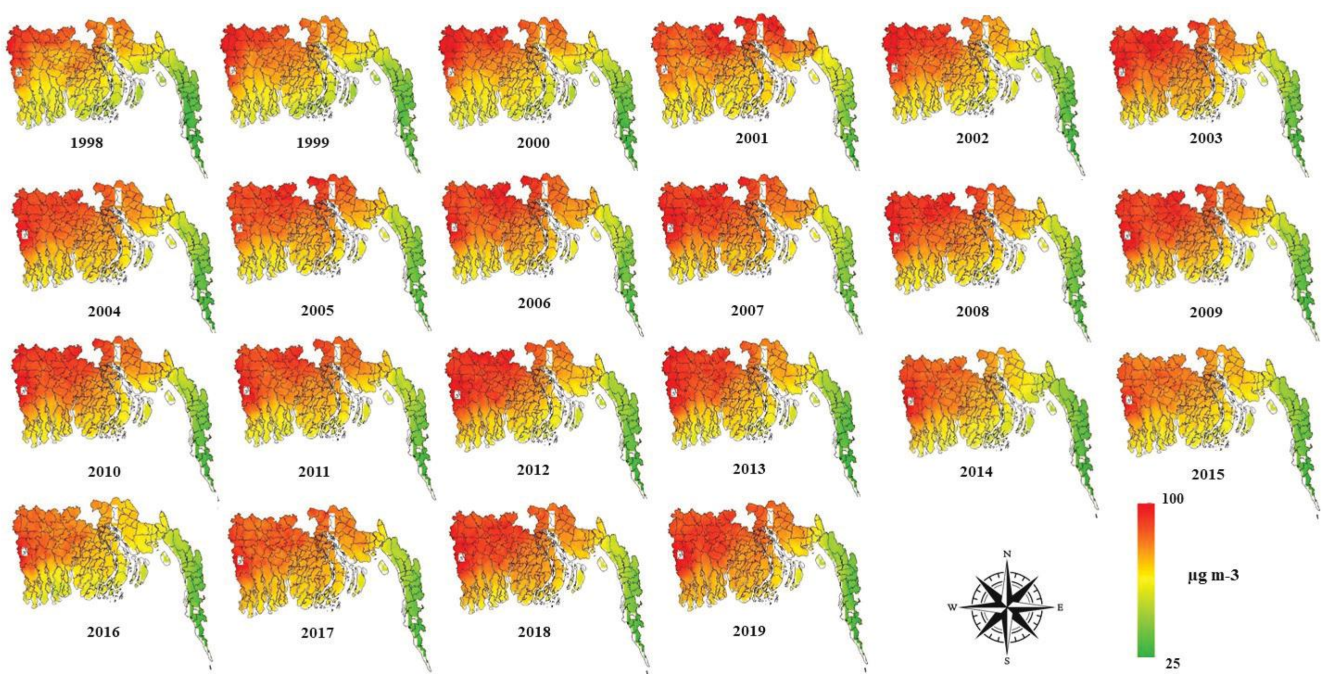


**Figure 7:** Spatial Distribution of $PM_{2.5}$ Concentrations in the Coastal Area of Bangladesh

## DISCUSSION

### Trend Analysis

Figure 8 depicts the research area through a trend analysis of four air pollutants ($NO_2$, $SO_2$, CO, and $O_3$). The regional and temporal trends between 2018 and 2022 were investigated using Mann-Kendall time series statistical tests in one segment and two seasons (dry season and wet season).

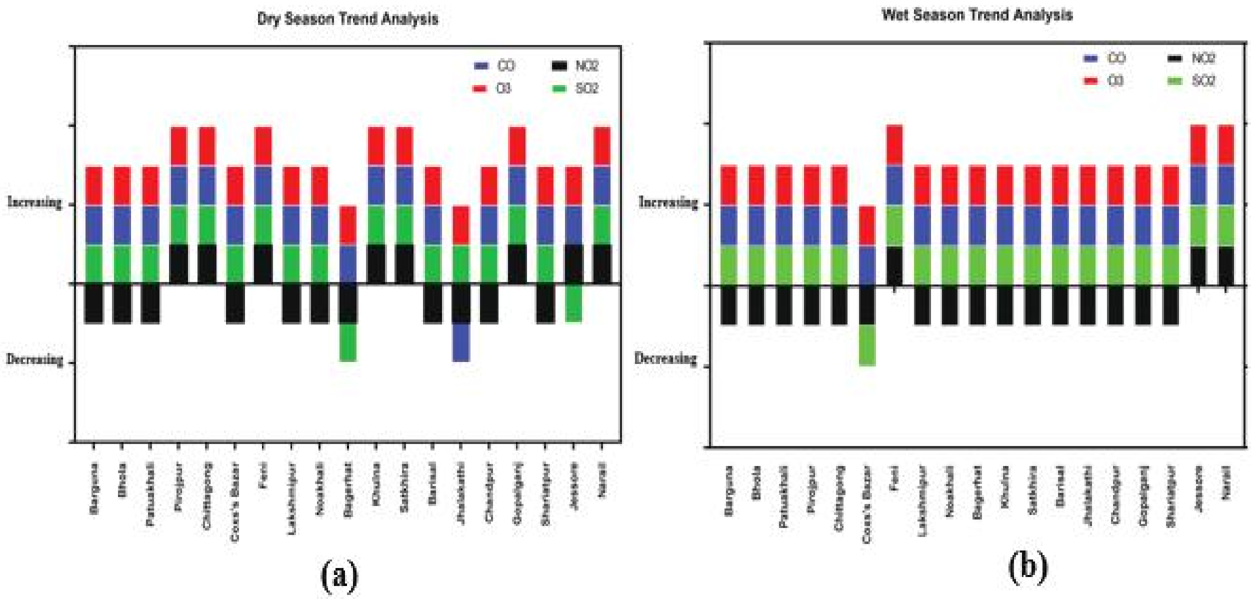


**Figure 8:** Trend Analysis of $NO_2$, $SO_2$, CO and $O_3$ in (a) Dry Season and (b) Wet Season

During dry season, $NO_2$ content showed non-significant decreasing trend in Cox's Bazar, Barguna, Bagerhat, Barisal, Bhola, Patuakhali, Lakshmipur, Noakhali, Jhalakathi, Chandpur, and Shariatpur and rest of the districts showed non-significant increasing trend, over the period from 2018-2022. In wet season, $NO_2$ content showed non-significant increasing trend in Feni, Jashore and Narail and rest of the districts showed non-significant decreasing trend, during 2018-2022 period. Hence, strong $NO_2$ reductions were observed in trend analysis in the Bangladesh's coastal region according to TROPOMI $NO_2$ observations. The regions with the most significant $NO_2$ sources closely match the regions with dense industrial clusters where electricity was generated by burning fossil fuels in $NO_2$-emitting power plants. TROPOMI measured $NO_2$ concentration which also showed a decreasing trend during the COVID-19 lock down time (2020 and 2021). In Bangladesh's coastline region, a distinct seasonal pattern was observed. where $NO_2$ concentration was higher in dry season than wet season (Fig. 8). Anthropogenic activity sources and industrial emission sources, which drastically dropped throughout the lockdown, can be responsible for the lower $NO_2$ concentration throughout the majority of interior coast.

In Bagerhat and Jashore, the $SO_2$ content showed a negligible declining trend in the dry season and rest of the districts showed non-significant rising trend, over the period from 2018-2022. In wet season, $SO_2$ content showed non-significant decreasing trend in Cox's Bazar and rest of the districts showed non-significant upward trend, during 2018-2022 period. The coastal area of Bangladesh showed a strong $SO_2$ increase in Trend Analysis. However, the CO content decreased in Jhalakathi non-significantly throughout the dry season and rest of the districts showed non-significant rising trend, over the period from 2018-2022. In wet season, CO content showed non-significant rising trend in all the district of the coastal area of Bangladesh, during 2018-2022 period. Therefore, trend analysis in Bangladesh's Coastal Area showed a strong CO increase. The $O_3$ content during the dry season indicated a non-significant increasing trend over Bangladesh's coastal region from 2018 to 2022. In wet season, $O_3$ content showed non-significant increasing trend in all the districts of the coastal area of Bangladesh, during 2018-2022 period. The analysis of atmospheric $PM_{2.5}$ data from 1998 to 2019 performed in the present study revealed that during the time series, $PM_{2.5}$ content showed significant (95%) increasing trend in all of the coastal districts, over the period from 1998-2019 (Fig. 9).

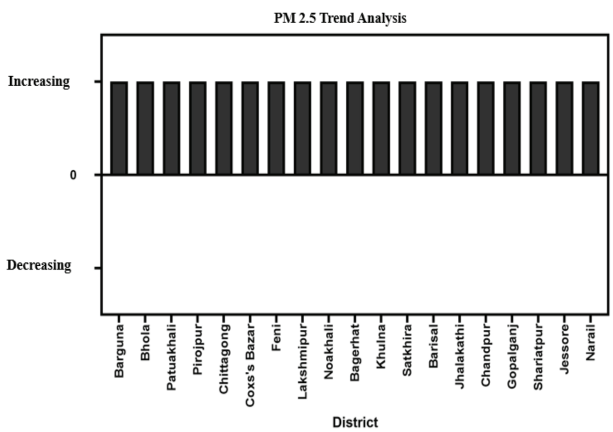


**Figure 9:** Trend Analysis from 1998-2019 of $PM_{2.5}$

All of the coastal districts have $PM_{2.5}$ concentrations that are higher than the BNAAQS. (Bangladesh National Ambient Air Quality Standards) standard which was 15 µg $m^{-3}$/Annual.

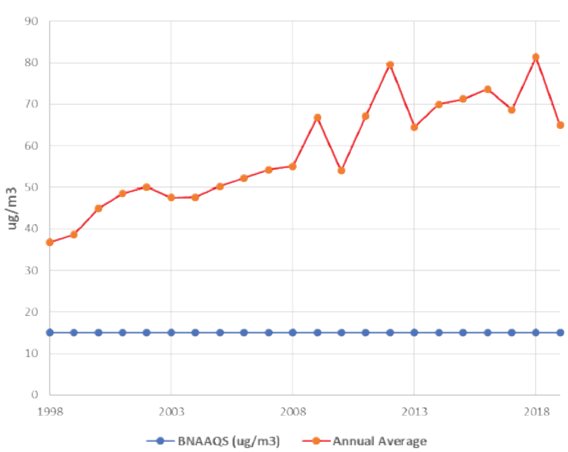


**Figure 10:** Comparison of $PM_{2.5}$ Annual Average with BNAAQS

## Comparison between Exposed and Interior Coast

The average $PM_{2.5}$ concentration of interior coast was 65.87 µg $m^{-3}$ and exposed coast was 55.94 µg $m^{-3}$. Interior coast was found polluted than the exposed coast. Interior coast is adjacent to the capital city Dhaka. Dhaka city is one of the most polluted cities in the world. Pollutants are quickly diluted and carried away by the winds. The most of the major industrial areas were close to Dhaka. This could be a reason for the high concentration of $PM_{2.5}$ in interior coastal region.

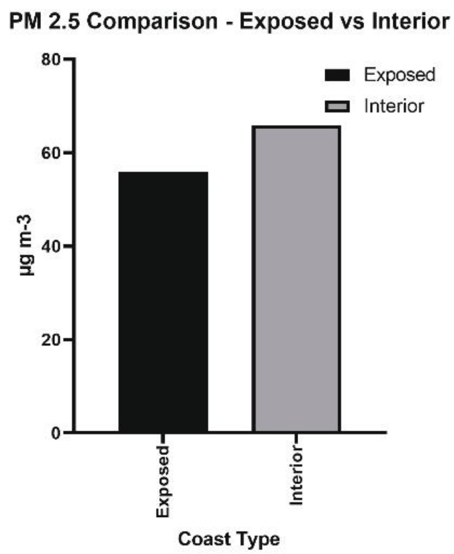


**Figure 11:** $PM_{2.5}$ Comparison between Exposed and Interior Coasts

The study found that the concentration of $NO_2$ was much higher on the interior coast than the exposed coast. Figure 12 (a) showed that all the values were higher in the interior coast. In dry season, the average $NO_2$ concentration of the interior coast was found 70.82 mol/$m^2$ and exposed coast was 33.58 mol/$m^2$ and in the wet season, the average $NO_2$ concentration of interior coast was found 39.48 mol/$m^2$ and exposed coast was 28.53 mol/$m^2$. In the dry season, the average $SO_2$ concentration of the interior coast was found 1039.25 mol/$m^2$ and exposed coast was 1112.36 mol/$m^2$ in the wet season, the average $SO_2$ concentration of interior coast was found 492.53 mol/$m^2$ and exposed coast was 475.75 mol/$m^2$. Therefore, it was found that the exposed coast was more polluted than the interior coast in dry season. In wet seasons, the interior coast was found to be more polluted than the exposed coast. However, the average CO concentration in interior coast during the dry season was found to be 0.0438 mol/$m^2$ and exposed coast was found 0.0423 mol/$m^2$ and in wet season, the average CO concentration of interior coast was found 0.0444 mol/$m^2$ and exposed coast was 0.0432 mol/$m^2$.

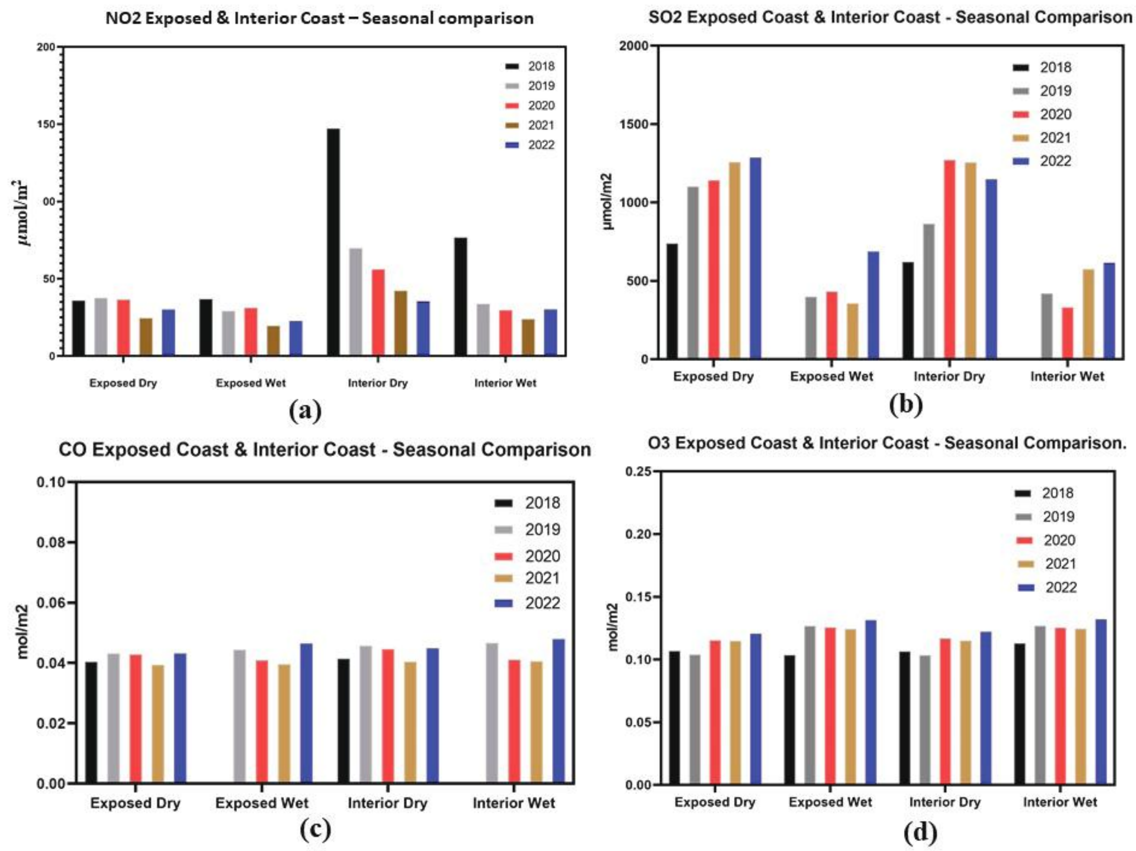


**Figure 12:** Seasonal Comparison between Exposed and Interior Coasts

Therefore, it was found that the interior coast was slightly more polluted than the exposed coast in dry season. In wet seasons, the interior coast was found to be more polluted than the exposed coast. In CO concentrations, it was found that wet season was more polluted than the dry season. The most polluted year, in terms of CO yearly average concentration, was found to be 2022. The average $O_3$ concentration in interior coast during the dry season was found to be 0.1136 mol/m$^2$ and exposed coast was found 0.1131 mol/m$^2$ and in the wet season, the average $O_3$ concentration of interior coast was found 0.125 mol/m$^2$ and exposed coast was 0.123 mol/m$^2$. Therefore, it was found that in both seasons the interior coast was slightly more polluted than the exposed coast.

## CONCLUSIONS

The study identified that the $PM_{2.5}$ concentrations were observed well above the BNAAQS value. The trends of the maximum pollutants were increasing meaning that the pollution was increasing all over the coastal area of Bangladesh. Bagerhat and Jashore show decreasing trends in dry season and the rest of the districts were found increasing in trend analysis. It was found that the interior coast was more highly polluted than the exposed coast. It has been identified that pollutants are produced more by the road traffic sector, commercial and industrial operations in interior coast, along with a number of brick kilns, which significantly increased emissions. Cox's Bazar and Chattogram were found as less polluted and Khulna, Jashore, Satkhira, Narail, Chandpur, Shariatpur, and Lakshmipur were found as the most polluted cities. The study also found that the dry season was more polluted than wet season. The degree of air pollution, its impacts, and local and national improvement strategies may have been better understood with the help of seasonal analysis. The prevalence of air pollution is primarily due to the presence of these pollutants, making it imperative for policymakers and urban planners to implement measures to lower their concentrations. Identifying the sources of these pollutants is crucial in effectively managing air pollution. The current study uses remotely sensed data to create a map of air pollution levels in the coastal area of Bangladesh. However, to validate and further understand the findings of the study, future research could incorporate ground-level data to provide a more comprehensive analysis of the impacts of air pollution on the environment and human health. This would involve collecting empirical data on air pollution levels, sources of pollution, and potential health effects. By combining the data from remote sensing with ground-level data, researchers can create a more accurate and detailed picture of air pollution in the research area. This would help policymakers and urban planners to develop more effective strategies to reduce air pollution and protect public health.

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