IDENTIFICATION OF NO_2 AND SO_2 POLLUTION, TRENDS AND SOURCES IN BANGLADESH

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ABSTRACT

Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are two major atmospheric pollutants that significantly threaten human health, the environment, and ecosystems. Bangladesh is vulnerable to NO_2 and SO_2. This study investigated the pollution, trend, sources of NO_2 and SO_2 suing OMI (Ozone Monitoring Instrument) data from 2005-2020 at all divisional city of Bangladesh. The study found that mean annual NO_2 of all cities 0.18±0.07 DU while mean annual SO_2 is 0.19±0.07 DU. Seasonal mean NO_2 was highest at Rajshahi (0.25 ± 0.08 DU) in winter and SO_2 was highest at Dhaka (0.25 ± 0.08 DU). Emission of NO_2 and SO_2 is higher in winter followed by spring, summer, and autumn in Bangladesh due to brick kiln production, brick field, biomass burning. Emission found lower in summer due to heavy precipitation, which washes out the pollution from the atmosphere. Frequency occurrence of NO_2 and SO_2 was high in winter which is basically November and December. High SO_2/ NO_2 ratio (~46) indicates significant annual and seasonal variations. Trends in NO_2 and SO_2 were calculated for 2005-2020 which showed mostly increasing trend at cities for NO_2 and SO_2. Increasing trend is alarming for the countries air quality which should be taken under control.

Keywords: *NO_2, SO_2, pollution, Bangladesh, trend*

INTRODUCTION

Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are the two most critical gaseous pollutants that affects regional and global air quality, human health, ecological conditions, and climate change (Ghosh et al., 2017; Wang et al., 2021). These have significant effects on human health (asthma and cancer) (Slezakova et al., 2011; Hao et al., 2014; Wang et al., 2021). Both the United States Environmental Protection Agency (US EPA) and the World Health Organization (WHO) consider NO_2 as a severe pollutant (Herron-Thorpe et al., 2010; Melamed et al., 2016). Since NO_2 and SO_2 are poisonous, they pose severe risks to biodiversity. A mixture of NO_2 and SO_2 is more harmful to plants (Barker and Tingey 2012). Moreover, the presence of SO_2 contributes to acid rain, ozone depletion, and respiratory conditions like asthma in humans (Niu et al., 2011; Su et al., 2013). NO_2 and SO_2 pollution exists in Europe, Africa, and North America, where industrial activities are prominent. South Asian countries are also large contributor of air pollutant. Bangladesh is one of the significant contributors of NO_2 and SO_2. NO_2 is primarily released from the industrial burning of fossil fuels, coal and gas combustions, vehicle exhaust, biomass burning, and electricity generation. On the other hand, SO_2 is released from domestic heating, burning fossil fuels that contain sulfur, power generation, industrial activities, power plants, and biomass burning **(**Islam et al., 2022**).**

South Asian countries are identified as the hotspot of air pollution since last two decades (Burnett et al., 2018**).** According to IQAir, Bangladesh was the most air polluted country in 2019 (IQAir, 2020). NO_2 and SO_2 are two main pollutants of the country. Considering diverse impacts and action associated of SO_2 and NO_2, pollution and emission of both gas is major problem of Bangladesh which is increasing day by day. Bangladesh is considered as world's most polluted country while industry and heavy traffic is the main reason behind the air pollution. NO_2 and SO_2 pollution is dangerous and it will become worse day by day. This study focused on how this two pollutant are existing and overall scenario.

METHODOLOGY

Study Area

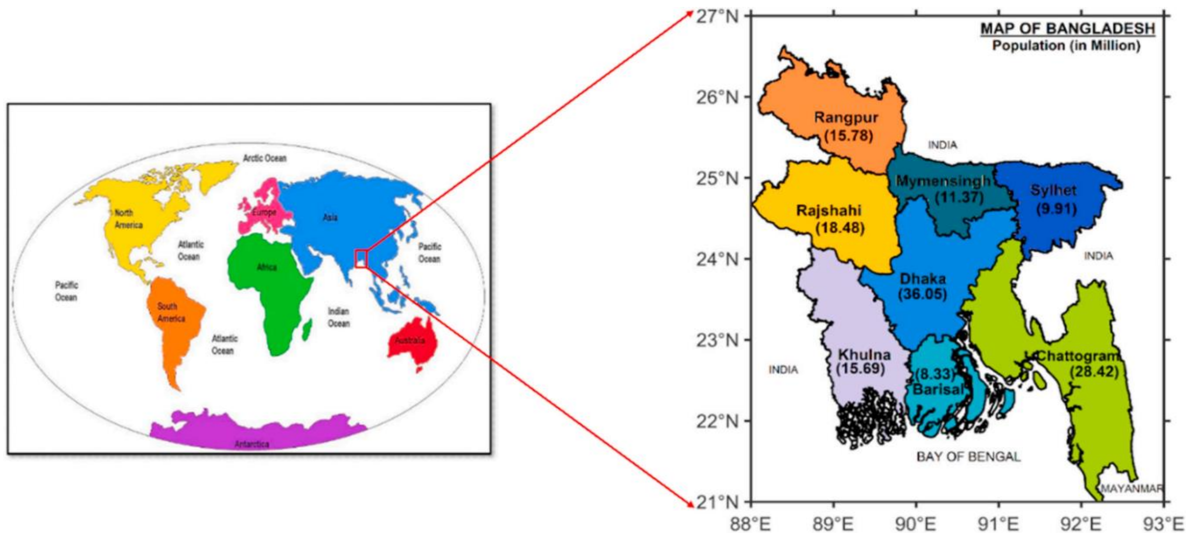


Fig 1: Map of study area including all divisions and populations (millions). (Source: Ali et al., 2022).

This study was focused on Bangladesh. The country is located in South Asia at 20°34' -26°38' N and 88°01'-92°42' E (Qiu et al., 2021). The country has high population density of 1265 people per km^2 (Islam et al., 2021).

OMI Data

NO_2 and SO_2 data that are used for this study is OMI (Ozone Monitoring Instrument) data. The Ozone Monitoring Instrument (OMI), which was launched on July 15, 2004, is a sun-synchronous satellite called Aura that tracks at a height of 705 km. It crosses at approximately 1:45 p.m. (local time). With daily global coverage and a spatial resolution of 13×25 km at nadir, it is a hyperspectral sensor that monitors the reflected radiation from the earth-atmosphere system utilizing wavelengths of 250–500 (nm). In order to get the absorbing aerosol optical depth (AAOD, 388 nm), the ultraviolet aerosol index (UVAI), the AOD, and the SSA, the OMI sensor utilizes the OMAERUV algorithm (Torres et al., 2013). Additionally, this sensor offers ambient trace gases (e.g., O_3, NO_2, and SO_2) (Carn et al., 2017; Bilal et al., 2021). Long-term (2005-2020) OMAERUV version 3, level 3 daily cloud-screened (cloud fraction < 30%) total column NO_2 (OMNO2d) and SO_2 (cloud radiance fraction < 0.2, OMSO2e) products at a spatial resolution of 0.25° × 0.25° were used in this study. All the NO_2 and SO_2 data were downloaded from https://giovanni.gsfc.nasa.gov/.

Methods

Trend analysis

Mann-Kendal test

To calculate the NO_2 and SO_2 trends Mann-Kendal test was applied and Sen's slope method was used to evaluate the properties. Steps that are followed to calculate trends are as follows:

If x_1, x_2, x_3 …… x_i represent n data points where x_i represents the data point at time i, then the Mann–Kendall statistic and Sen's slope (S, Equations (1) and (2)) is given by (Mann 1945; Kendall 1948).

$$s = \Sigma_{k=1}^{n-1}\Sigma_{i=k+1}^{n} sign(x_i\text{-}x_k) \quad (1)$$

Where

$$sign\ (x_i - x_k) = \begin{cases} 1, if\ (x_i - x_k) & > 0 \\ 0, \quad if (x_i - x_k) & = 0 \\ -1, if\ (x_i - x_k) & < 0 \end{cases} \quad (2)$$

The probability associated with **S** and the sample size, n, were calculated to quantify the significance of NO_2 and SO_2 trends based on the normalized statistics (Z, Equation (3)):

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}}, if\ S > 0 \\ 0, \quad\quad if\ S = 0 \\ \frac{S-1}{\sqrt{VAR(S)}}, if\ S < 0 \end{cases} \quad (3)$$

At the 95% significance level, the null hypothesis of no trend is rejected if |Z| > 1.96. Sen's slope (Sen 1968) method was applied to derive the slope as a measure of change per unit time (Equation 4):

Sen's slope method

$$Q' = \frac{x_{t'} - x_t}{t' - t} \quad (4)$$

Where, Q'= slope between data points $\mathbf{x_{t'}}$ and $\mathbf{x_t}$, $\mathbf{x_{t'}}$= data measurement at a time $\mathbf{t'}$, and x_t = data measurement at time t.

Sen's estimator of the slope is acquired based on the median slope

$$Q = Q'[N+1/2] \quad \text{if N is odd}$$

$$= (Q'_{\left[\frac{N}{2}\right]} + Q'_{[(N+2)/2]})/2 \quad \text{if N is even} \quad (5)$$

where N is the number of calculated slopes.

Materials

To perform all the analysis, several software was used. Origin pro, RStudio, Arc GIS 10.8, Mendeley v1.19.8. Whole study written using MS word 2019.

RESULTS

Annual Mean Concentration of NO_2 and SO_2

Average NO_2 over eight divisional cities of Bangladesh are showing in table 1. For the 8 studied cities, the 16-year city-level annual mean NO_2 concentration was highest in Dhaka (0.25 ± 0.09 DU) and lowest in Chittagong (0.12 ± 0.03DU). The seasonal mean NO_2 was highest in Rajshahi (0.25 ± 0.08) at winter and lowermost in Barisal and Chittagong (0.12 ± 0.03 DU) at summer (Table 1).

Table 1: City averaged annual mean of NO2 (± STD) (DU) obtained from OMI from 2005 to 2020 in 8 division of Bangladesh.

Year	Rangpur	Rajshahi	Khulna	Barishal	Chittagong	Sylhet	Mymensingh	Dhaka
2005	0.14 ± 0.10	0.15 ± 0.10	0.16 ± 0.04	0.14 ± 0.03	0.12 ± 0.03	0.14 ± 0.03	0.15 ± 0.03	0.19 ± 0.05
2006	0.13 ± 0.07	0.16 ± 0.10	0.16 ± 0.04	0.13 ± 0.03	0.12 ± 0.03	0.14 ± 0.04	0.15 ± 0.04	0.19 ± 0.05
2007	0.14 ± 0.07	0.15 ± 0.10	0.16 ± 0.05	0.15 ± 0.03	0.13 ± 0.03	0.15 ± 0.03	0.15 ± 0.03	0.19 ± 0.06
2008	0.17 ± 0.04	0.15 ± 0.10	0.16 ± 0.04	0.15 ± 0.04	0.14 ± 0.04	0.14 ± 0.03	0.15 ± 0.03	0.21 ± 0.08
2009	0.19 ± 0.04	0.22 ± 0.07	0.18 ± 0.04	0.15 ± 0.04	0.12 ± 0.03	0.16 ± 0.04	0.16 ± 0.04	0.21 ± 0.05
2010	0.18 ± 0.04	0.21 ± 0.07	0.17 ± 0.04	0.15 ± 0.03	0.13 ± 0.03	0.15 ± 0.03	0.16 ± 0.04	0.21 ± 0.06
2011	0.19 ± 0.05	0.22 ± 0.08	0.18 ± 0.05	0.16 ± 0.04	0.14 ± 0.03	0.16 ± 0.04	0.17 ± 0.04	0.24 ± 0.09
2012	0.18 ± 0.05	0.23 ± 0.08	0.17 ± 0.04	0.16 ± 0.03	0.13 ± 0.03	0.16 ± 0.03	0.17 ± 0.04	0.22 ± 0.07
2013	0.18 ± 0.04	0.21 ± 0.06	0.17 ± 0.05	0.15 ± 0.03	0.12 ± 0.03	0.15 ± 0.03	0.16 ± 0.04	0.22 ± 0.06
2014	0.19 ± 0.04	0.23 ± 0.07	0.18 ± 0.04	0.16 ± 0.03	0.14 ±0.04	0.16 ± 0.04	0.17 ± 0.04	0.23 ± 0.06
2015	0.16 ± 0.06	0.21 ± 0.07	0.16 ± 0.04	0.15 ± 0.04	0.13 ± 0.03	0.15 ± 0.03	0.15 ± 0.03	0.21 ± 0.08
2016	0.20 ± 0.05	0.23 ± 0.07	0.19 ± 0.04	0.17 ± 0.04	0.14 ± 0.03	0.16 ± 0.04	0.17 ± 0.04	0.25 ± 0.08
2017	0.19 ± 0.05	0.23 ± 0.07	0.18 ± 0.04	0.18 ± 0.03	0.14 ± 0.03	0.16 ± 0.04	0.17 ± 0.03	0.25 ± 0.09
2018	0.19 ± 0.04	0.23 ± 0.07	0.18 ± 0.05	0.17 ± 0.03	0.14 ± 0.04	0.16 ± 0.04	0.17 ± 0.05	0.25 ± 0.07
2019	0.19 ± 0.05	0.22 ± 0.06	0.17 ± 0.04	0.16 ± 0.05	0.14 ± 0.04	0.16 ± 0.04	0.17 ± 0.04	0.24 ± 0.08
2020	0.18 ± 0.04	0.21 ± 0.08	0.16 ± 0.04	0.15 ± 0.04	0.13 ± 0.04	0.15 ± 0.04	0.17 ± 0.04	0.22 ± 0.10

Average NO_2 values for 8 cities were close to each other, which indicating that the existence of significant gaseous pollutant emissions in Bangladesh. which strongly impacted by the intense anthropogenic emissions, resulting from several anthropogenic emissions from point sources like high traffic volumes, large scale industrial activities. Dhaka, the capital city of Bangladesh has the highest emission in study period. Dense population, high volume of electricity generation are the causes behind existing NO_2. Except Dhaka, Rangpur and Rajshahi city also has moderate level of emission which is because of large number of brick kilns there. Comparing to other cities of the world like Wuxi of China (0.78 ± 0.09 DU) (Wang et al, 2021); overall annual mean of Bangladesh is quite low. Brick kilns are actively contributed to NO_2 about 6 months of the year. Coal based power plant; coal mining area existing in Rangpur region which is also a reason behind higher NO_2 emission. Seasonally, NO_2 were found highest winter followed by spring, summer, and autumn. Spatial distribution of seasonal NO_2 showed the seasonal concentration over cities. Winter contains high NO_2 emission because like summer, NO_2 didn't wash out through rain water. Following table 2 showing seasonal mean concentration of NO_2. Highest NO_2 found at Rajshahi (0.25 ± 0.08).

Table 2: City averaged seasonal mean of NO_2 (± STD) (DU) obtained from OMI from 2005 to 2020 in 8 division of Bangladesh.

City	Winter	Spring	Summer	Autumn
Rangpur	0.21 ± 0.05	0.23 ± 0.04	0.18 ± 0.03	0.17 ± 0.03
Rajshahi	0.25 ± 0.08	0.24 ± 0.04	0.19 ± 0.04	0.20 ± 0.11
Khulna	0.20 ± 0.05	0.19 ± 0.04	0.16 ± 0.05	0.17 ± 0.04
Barishal	0.13 ± 0.03	0.14 ± 0.02	0.12 ± 0.03	0.15 ± 0.04
Chittagong	0.18 ± 0.04	0.14 ± 0.05	0.12 ± 0.03	0.12 ± 0.02
Sylhet	0.17 ± 0.03	0.16 ± 0.03	0.16 ± 0.04	0.15 ± 0.04
Mymensingh	0.18 ± 0.03	0.19 ± 0.03	0.16 ± 0.03	0.16 ± 0.04
Dhaka	0.24 ± 0.08	0.23 ± 0.06	0.18 ± 0.04	0.21 ± 0.07

Annual average concentration of SO_2 showed in the table 4.3 with STD. For the 8 studied cities, the 16-year city-level annual mean of SO_2 concentration found highest in Rajshahi (0.44 ±0.08 DU) and lowest in Mymensingh (0.10 ± 0.09 DU). This level of annual SO_2 is lower than other city level SO_2 such as Chinese city Xuzhou (0.63 ± 0.16 DU).

Table 3: City averaged annual mean of SO_2 (± STD) (DU) obtained from OMI from 2005 to 2020 in 8 division of Bangladesh.

Year	**Rangpur**	**Rajshahi**	**Khulna**	**Barisal**	**Chittagong**	**Sylhet**	**Mymensingh**	**Dhaka**
2005	0.20±0.08	0.19± 0.06	0.17 ±0.03	0.25±0.05	0.20 ±0.09	0.16 ± 0.04	0.21 ±0.09	0.17 ±0.07
2006	0.25 ±0.09	0.44 ±0.08	0.42 ± 0.03	0.20±0.08	0.22 ±0.07	0.22±0.05	0.17 ±0.1	0.23 ±0.07
2007	0.16 ±0.07	0.17 ±0.05	0.15 ±0.04	0.13±0.05	0.17 ±0.08	0.15± 0.05	0.09 ±0.08	0.16 ±0.07
2008	0.38 ±0.08	0.30±0.06	0.28 ±0.04	0.13±0.06	0.21±0.07	0.16± 0.06	0.16 ±0.09	0.16 ±0.08
2009	0.19 ±0.08	0.16±0.09	0.14 ±0.04	0.12±0.05	0.17 ±0.07	0.14± 0.09	0.14 ±0.09	0.15 ±0.09
2010	0.20 ±0.09	0.22 ±0.07	0.20 ±0.04	0.16±0.06	0.14±0.08	0.16± 0.04	0.13 ±0.1	0.17 ±0.07
2011	0.22 ±0.07	0.28±0.06	0.26 ±0.04	0.13 ± 0.06	0.15±0.08	0.15±0.08	0.15±0.08	0.16 ±0.08
2012	0.17 ±0.08	0.14±0.08	0.12 ±0.04	0.12±0.04	0.20 ±0.08	0.20 ±0.09	0.10 ±0.09	0.20±0.07
2013	0.21±0.07	0.26±0.05	0.24 ±0.03	0.12±0.06	0.18 ±0.09	0.14±0.04	0.14±0.08	0.15 ±0.09
2014	0.17 ±0.07	0.18±0.06	0.16 ±0.04	0.16± 0.08	0.15 ±0.04	0.16± 0.06	0.15±0.08	0.17 ±0.07
2015	0.29 ±0.07	0.31 ±0.09	0.29±0.03	0.13±0.06	0.28 ±0.04	0.18±0.02	0.20 ±0.08	0.19±0.08
2016	0.26±0.08	0.28±0.07	0.26±0.05	0.14±0.05	0.14 ±0.04	0.15±.08	0.18 ±0.09	0.16 ±0.08
2017	0.22±0.09	0.18 ±0.05	0.16±0.04	0.17±0.06	0.20 ±0.04	0.17±0.07	0.17 ±0.1	0.17 ±0.09
2018	0.24±0.07	0.28 ±0.06	0.26±0.04	0.13±0.06	0.23 ±0.07	0.19±.08	0.18 ±0.08	0.20 ±0.07
2019	0.23±0.08	0.27±0.09	0.25±0.03	0.17±0.06	0.16 ±0.07	0.15±0.04	0.14 ±0.09	0.16 ±0.08
2020	0.21±0.07	0.18 ±0.07	0.16±0.04	0.21±0.08	0.16 ±0.08	0.23±0.07	0.17 ±0.08	0.24 ±0.07

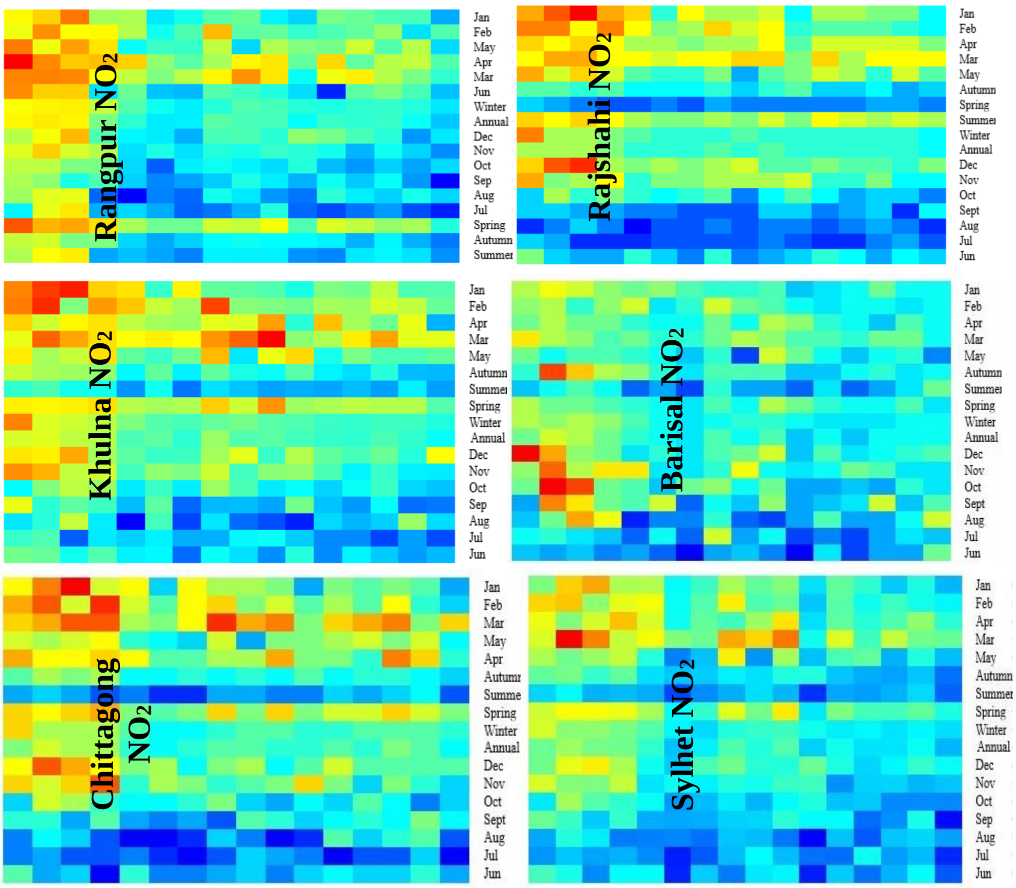
Seasonally, SO_2 were found highest winter followed by spring, summer, and autumn. Winter contains high SO_2 emission because like summer, SO_2 didn't wash out through rain water. Following table 3 showing seasonal mean concentration of SO_2.

Table 4: City averaged seasonal mean of SO_2 (± STD) (DU) obtained from OMI from 2005 to 2020 in 8 division of Bangladesh.

City	Winter	Spring	Summer	Autumn
Rangpur	0.23 ± 0.05	0.21 ± 0.04	0.17 ± 0.03	0.14 ± 0.03
Rajshahi	0.22 ± 0.08	0.21 ± 0.04	0.21 ± 0.04	0.20 ± 0.11
Khulna	0.22 ± 0.05	0.18 ± 0.04	0.20 ± 0.05	0.16 ± 0.04
Barishal	0.23 ± 0.03	0.16 ± 0.02	0.19 ± 0.03	0.18 ± 0.04
Chittagong	0.19 ± 0.04	0.17 ± 0.05	0.17 ± 0.03	0.19 ± 0.02
Sylhet	0.20 ± 0.03	0.19 ± 0.03	0.15 ± 0.04	0.16 ± 0.04
Mymensingh	0.18 ± 0.03	0.18 ± 0.03	0.18 ± 0.03	0.13 ± 0.04
Dhaka	0.26 ± 0.08	0.24 ± 0.06	0.19 ± 0.04	0.17 ± 0.07

Frequency Distributions of NO_2 and SO_2

City based Frequency distribution shows overall occurences and level of both NO_2 and SO_2.



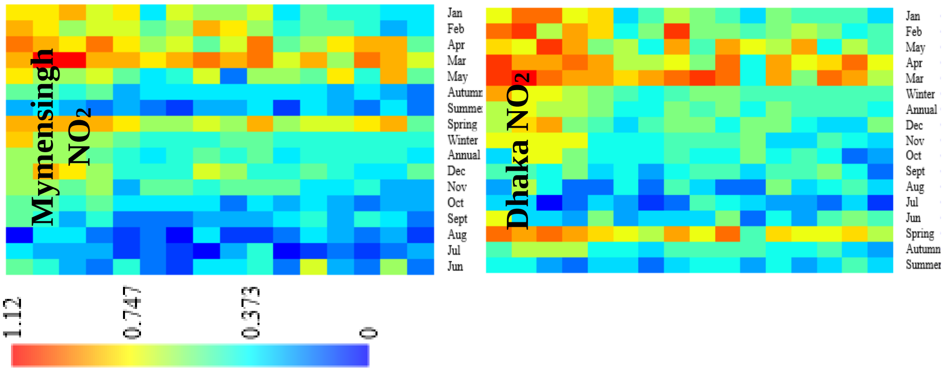


Fig 2: Annual and seasonal frequency distributions of OMI-retrieved total column NO_2 (DU) in Bangladesh from 2005 to 2020

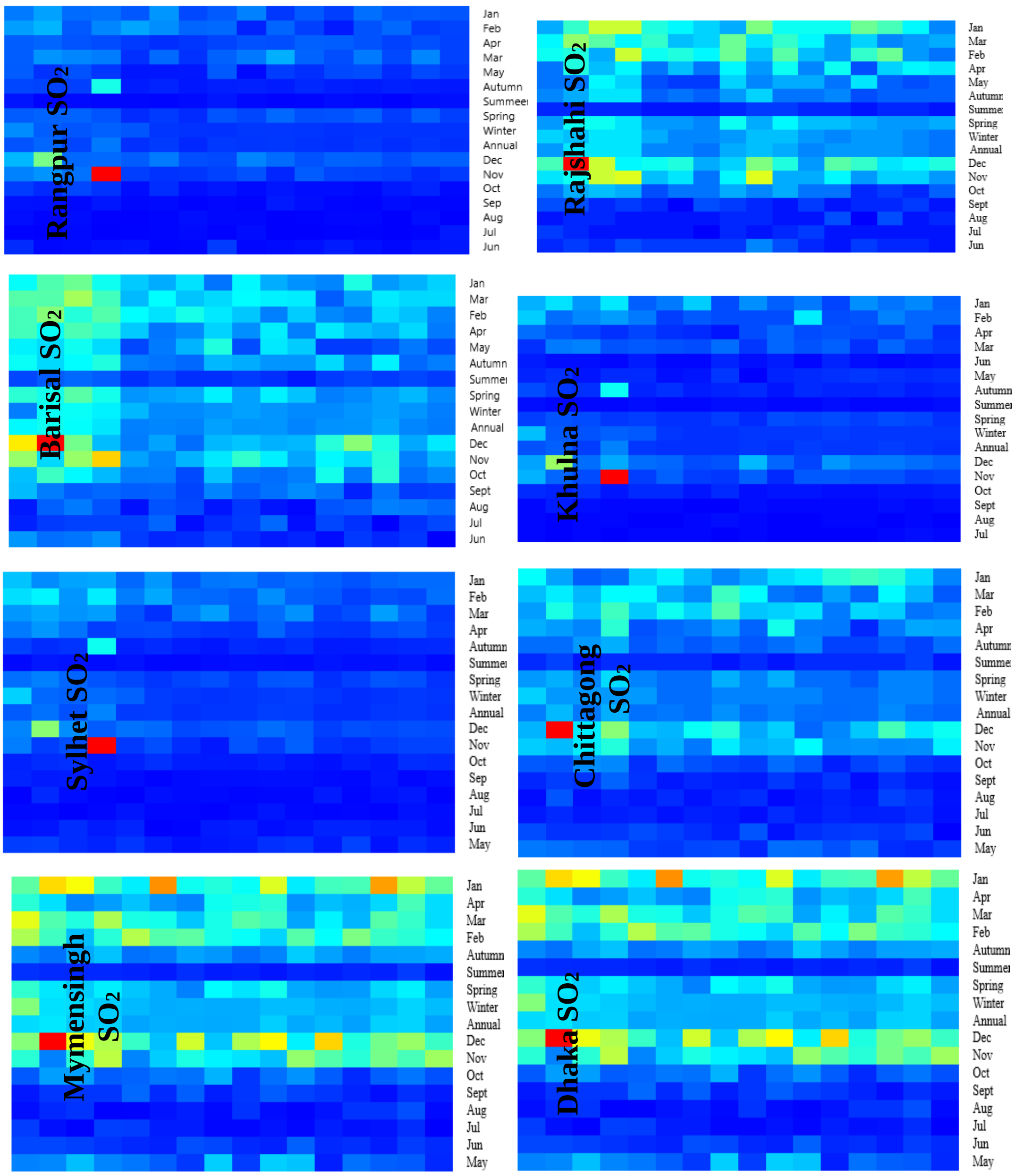


Fig 3: Annual and seasonal frequency distributions of OMI-retrieved total column SO_2 (DU) in Bangladesh from 2005 to 2020

Frequency distribution of pollutants showed how both NO_2 and SO_2 are present annually, seasonally and monthly on all divisional cities in Bangladesh. From above figures, its evident that level of NO_2 is greater than SO_2. Highest frequency of both NO_2 and SO_2 is 1.12 and the lowest is 0. Overall, January to March is the month when frequency of NO_2were highy compared to other months of the year. In term of season, Spring and winter has intense NO_2 pollution compared to summer and autumn. Sylhet and Barishal city has lower pollution of nitrogen dioxide. Conversely, Rangpur, Dhaka, Mymensingh, Khulna, Chittagong has high level pollution due evident sources of NO_2.
On the other hand, SO_2 found very low all over thew countries. Among all the cities, Dhaka, Mymensingh, Rajshahi, and Barishal has the higher level of SO_2 pollution. November, December, January was the month when pollution were high. Dhaka showed high level of pollution in terms of both pollutant because high industrial activities, consuntruction activities, excessive number of vehicular emssion.

Ratio of NO_2/SO_2 Indicator for Pollution Level

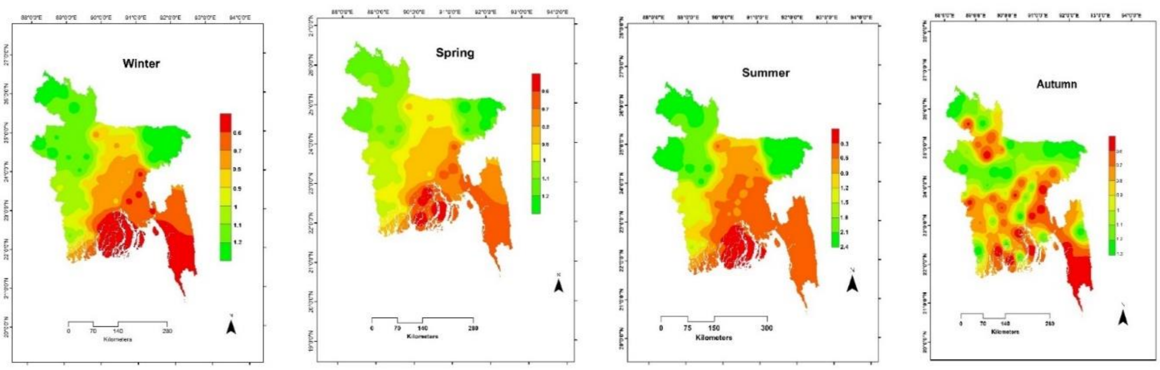


Fig 4: Seasonal spatial distribution of SO_2/NO_2 ratio of Bangladesh from 2005 to 2020

Examining the sources of air pollution (mobile sources like traffic emissions and point sources like industrial operations) involved using the SO_2/NO_2 ratio. Seasonal ratio of SO_2/NO_2 of winter is highest at Rajshahi (~1.03) that indicates higher contributions from several point sources and lower at Sylhet (~0.68). In spring, highest ratio found at Rajshahi (~1.02) and lowest at Sylhet (~0.59). In summer, highest ratio found at Khulna (~2.01) and lowest at Rangpur (~0.21). In autumn, highest ratio found at Rajshahi (~1.26) and lowest at Sylhet (~0.61). For all cities ratio, highest ratio was found Rajshahi (~1.06) and lowest was found at Sylhet (~0.67). In summer, SO_2/NO_2 ratio remains highest due to variation in SO_2 pollution. SO_2/NO_2 ratio values of 8 cities of Bangladesh were remarkably close to one another, indicating the significant contributions from industrial activities to NO_2 and SO_2 emissions. Industrial activities contribute to high SO_2 and high-sulfur coals are the reason for higher ratio of NO_2 and SO_2.

Sources of NO_2 and SO_2

Fossil fuel combustion, industrial emissions, automobile emissions, biomass burning, natural lightning, and brick kiln emissions are the main sources of NO_2 at major cities in Bangladesh (Bilal et al., 2021). In contrast, coal, oil and gas, electricity generation, wood burning, over fertilization are the major contributors to anthropogenic SO_2 emissions (Wang et al., 2021). In Bangladesh NO_2 and SO_2 generates from many sources such as industrial activities; biomass burning; thermal power plants, electricity generation; fossil fuel (coal, oil, gas, kerosene) combustion; brick production and brick kilns (Rabbi. et al., 2018; Kang et al., 2019; Islam et al., 2022; Sikder et al., 2010; Kiros et al., 2016; Rahman et al., 2019; Mukta et al., 2020). Sulfur comes from combustion (Lu et al., 2013). Almost all sources of NO_2 and SO_2 are the same. Emissions from aircraft, LPG (Liquefied Petroleum gas) apparatus, wood burning, over-fertilization, and power stations are also significant sources of NO_2 and SO_2. In Bangladesh, the main sources of NO_2 emissions are the iron and steel industry, motor vehicles, biomass burning for domestic and industrial cooking, energy transformation enterprises, and the burning of agricultural leftovers (Ul-Haq et al., 2015). Many studies have generally described about several sources of both NO_2 and SO_2. Socioeconomic development, industrialization, and urbanization rates results higher NO_2 and SO_2. Most common source of NO_2 and SO_2 are industrial activities (Lin et al., 2019; Islam et al., 2022), biomass burning (Zheng et al., 2018; Lin et al., 2019) on purpose of running power plants (Ghosh et al., 2017; Lin et al., 2019), thermal power plants, electricity generation (Zheng et al., 2018; Wang et al., 2021); fossil fuel (coal, oil, gas, kerosene) combustion (Islam et al., 2022), vehicular emission (Lin et al., 2019; Islam et al., 2022), brick production and brick kilns and so on. In Bangladesh, diesel engine on motor vehicle is a point source of NO_2 pollution. Motor vehicles in Dhaka city is evident source of NO_2. Number of vehicles have increased in recent decades which results higher emission of NO_2. Metal refineries in Bangladesh is also an evident source of NO_2 (Rabbi. et al., 2018). Small or large garments industries near Dhaka (Gazipur, Savar, Narayanganj) is undoubtedly one ofb the main reason of higher NO_2 and SO_2 .

NO_2 and SO_2 Trends

To get a clear understanding of changes in OMI-based total column NO_2 and SO_2 (DU), city-level trends at annual timescales were calculated for the 8 cities of Bangladesh. Overall annual trend for all cities trend of NO_2 and SO_2 was mostly increasing trend and indicates significance for NO_2 and SO_2 trends at a 95% confidence level. Not all cities have statistically significant trend for pollutants. Following table is showing trend values for all cities. No decreasing trend was found from annual trend from all cities.

Table 5: Annual Trend of NO_2 and SO_2 for all cities

City	NO_2		SO_2	
	Z	P-value	Z	P-value
Rangpur	-2.66	0.0079	-2.2961	0.0221
Rajshahi	-3.65	0.0002	-1.936	0.0531
Khulna	-3.26	0.0011	-2.6563	0.0082
Barishal	-2.74	0.0060	-1.5758	0.1150
Chittagong	-2.93	0.0034	-2.4762	0.0131
Sylhet	-2.84	0.0045	-1.2645	0.0210
Mymensingh	-2.6	0.0093	-1.2645	0.2061
Dhaka	-1.76	0.0791	-1.3057	0.0191

CONCLUSIONS

This study evaluated long term (2005-2020) variation, trend of NO_2 and SO_2 pollution; ratio of this two pollutant, and sources of all division of Bangladesh. Major findings from this studies are-

- NO_2 and SO_2 found in most cities which are close to each other. Highest annual NO_2 was found in Dhaka (0.25 ± 0.09 DU) due to large industry and heavy traffic. On the other hand, SO_2 was found highest at Rajshahi (0.44 ±0.08 DU) and lowest in Mymensingh (0.10 ±0.09 DU)
- Seasonally, both NO_2 and SO_2 showed their highest values in winter due to increased anthropogenic emission activities such as brick kiln, brick production. In contrast, both NO_2

and SO_2 were lowest in summer due to heavy precipitation, which washes out the pollution from the atmosphere.

- High SO_2/NO_2 ratio values (2.01**)** indicate industry as the dominant source, with significant annual and seasonal fluctuations. The long-term (2005–2020) SO_2/NO_2 ratio showed its highest in Rajshahi (2.01) and lowest in Sylhet (0.61), suggesting that industrial activities contribute to high SO_2 pollution due to the use of high-sulfur coals. Seasonally, the SO_2/NO_2 ratio was highest in winter followed by summer, autumn and spring.
- Annually both NO_2 and SO_2 showed increasing trend from 2005-2020. Highest increasing trend of NO_2 was found at Dhaka (0.00791) and lowest was at Rajshahi (0.0002). In contrast, highest increasing trend of SO_2 was found at Rajshahi (0.0431) and lowest was at Khulna (0.0082).

Strategies for Reducing NO_2 and SO_2 Pollution

NO_2 and SO_2 pollution in Bangladesh is a threat which can be intensified if it is not taken under consideration. In order to control pollution and reduce the level of the two pollutants, some effective strategies should be taken. Here are some strategies for reducing NO_2 and SO_2 pollution:

Alternative fuels: Promoting cleaner fuels, such as compressed natural gas (CNG), liquefied petroleum gas (LPG), and biofuels, can significantly reduce NO_2 and SO_2 emissions from transportation and industrial sectors. Transitioning from fossil fuels to these cleaner alternatives can contribute to pollution reduction in Bangladesh.
Energy efficiency and conservation: Implementing energy efficiency measures in industries, buildings, and appliances can reduce energy consumption and subsequent emissions. This includes adopting
energy-efficient technologies, improving insulation and building design, and promoting energy conservation practices.
Renewable energy sources: Shifting towards renewable sources, such as solar, wind, and hydroelectric power, can help reduce NO_2 and SO_2 pollution from power generation. Governments and industries can incentivize and invest in renewable energy projects to accelerate the transition from fossil fuel-based energy production.
Vehicle emission standards: Governments should enforce stringent vehicle emission standards and regulations. This includes implementing emission testing programs, promoting low-emission vehicles (such as electric vehicles), and requiring regular maintenance and inspection of vehicles to ensure they meet emission standards.
Improving policy and legislation: Developing and implementing policies to address NO_2 and SO_2 pollution are necessary to curb pollution. The policy will include all commands and control methods useful to reduce pollution. Technological inventions and improvements will help reduce pollution. Proper policy implementation is essential to protect the environment and reduce pollution. City-specific climate policies and pollution control measures must be developed to minimize NO_2 and SO_2 pollution significantly.
This study identified the existing pollution trend and analyzed using long term data. This study focuses on sources, pollution, and trends of NO_2 and SO_2 of Bangladesh and this study also recommends some activities that can truly improve the pollution scenario. Recommendations are:

- ✓ Restrict the use of highly polluting plastic and coal-based fuels, reduce costs, and promote efficient industry and power generation fuel sources.
- ✓ There are examples of higher technological standards to reduce pollution from industry and transport catalytic converters, exhaust gas purifiers, and cleaner fuels.
- ✓ To fill the current knowledge gaps, comprehensive monitoring of NO_2 and SO_2 and identifying their sources is needed by establishing a reliable and continuous monitoring network in all the major cities of Bangladesh.
- ✓ Promoting public transportation and preventing or prohibiting the nation's use of poorly maintained or harmful vehicles.

- ✓ Promoting proper public debate, transparency policies encouraging companies to declare their emissions, and regulations encouraging decision makers to accept reasonable opinions in policy making.
- ✓ Expanding academic engagement and fostering a research and development culture in the industry.

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