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# Monitoring spatiotemporal changes of $NO_2$ using TROPOMI and sentinel-5 images for Dhaka city and its surrounding areas of Bangladesh

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ABSTRACT

**Introduction:** Discernable air pollution occurs in most developing countries due to rapid urbanization which can be parameterized by air, humidity, population density, temperature, contaminants, exorbitant fossil fuel consumption, and inadequate transportation. Nitrogen dioxide ($NO_2$), one of the most widely recognized air pollutants, has a detrimental impact on human health explicitly or implicitly and considerably influences on atmospheric composition.

**Materials and methods:** In this study, $NO_2$ intensity was analyzed from 2018 with aiming to monitor spatiotemporal changes in Dhaka and its surrounding areas with the Tropospheric Monitoring Instrument (TROPOMI) sensor data. Copernicus Sentinel-5 Precursor satellite data was used in the Google Earth Engine platform to get the result.

**Results:** The results revealed a strong relationship ($R^2$ =0.9478) between the $NO_2$ concentration and high population density and the temporal variation is higher during the pre-monsoon than throughout the post-monsoon. The reason behind is the lack of sunlight and the difficulty to break down the $NO_2$, which causes the removal of $NO_2$ from the atmosphere to proceed more slowly. In contrast, Land Use and Land Cover (LULC) are also impacted by the high concentration which is remains in the built-up area.

**Conclusion:** This research mainly considered that how $NO_2$ concentration measured from satellite images with temporal variation within a year and what factors strongly influence raising $NO_2$ levels. This model can be used for policy-making to take proper initiatives to reduce $NO_2$ concentrations. The result showed significant uses of TROPOMI with relating population density and LULC in Dhaka and its surrounding areas of Bangladesh.

## Introduction

In recent years, air pollution has raised severe concerns worldwide, especially in light of its several negative consequences on human health, the environment, the economy, culture, and customs, among other things [1]. The rapid oxidation of atmospheric Nitrogen dioxide ($NO_2$) results in the formation of nitrate aerosols, a primary source of airborne particles with a diameter of fewer than 2.5 µm ($PM_{2.5}$) [2]. By

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chemically reacting with atmospheric ozone, NO is easily transformed into the considerably more hazardous $NO_2$, resulting from this process and has a strong oxidant $NO_2$, odorless, pale yellow to bright red gas [1]. The causes of atmospheric pollution have greatly expanded in recent years due to accelerated economic growth and industrial operation [3]. The rise in $NO_2$ is a stark reminder of how dependent our economy is on the global combustion of fossil fuels [4]. The indicated air pollutant is $NO_2$, with the most excellent importance that requires routine monitoring near ozone or fine particles [5]. Combustion products are a known cause of respiratory symptoms and illnesses [6]. They are also bad for the environment because they act as a precursor to the synthesis of nitric acid, which causes acid rain [7].

The urban population of Bangladesh is indeed very exposed to climate change due to its high population growth, poor infrastructure, and little potential for adaptation [8]. Urban prosperity, development, consumption of resources, transportation systems, and modernization are still the principal variables influencing air quality. With an increasing global population comes an increasing impact of people on the natural environment of earth [9]. Population density and other covariates create an impact on the air quality. Population size and particle pollution have been proven to be positively associated [10]. When cities increase in population and inhabitants, more combustion occurs, more pollutants are produced by industry, and more people drive, each of which may negatively influence on environmental quality [11]. Urban air quality is mainly induced by the traffic congestion sector, which is the leading cause of pollution and is primarily evaluated in terms of $NO_2$ concentrations [12]. Population expansion is to blame for the abrupt change in land utilization because it causes built-up areas, the relocation of agricultural land, and degradation, which diminishes the amount of available land and obliterates habitat [13].

As ground stations are commonly used to monitor surface concentrations of air contaminants, this information is point-based and not spatially continuous. Additionally, since target pollutants frequently have uneven spatial distribution and are primarily concentrated in metropolitan areas, through in-ground measurements, it is difficult to determine these substances' spatial characteristics [3]. Since $NO_2$ species are formed during combustion processes, they can be used to estimate the amount of energy derived from fossil fuels and the number of greenhouse gases and other pollutants that are also released [14]. Numerous factors may affect $NO_2$ concentration in both time and space. One of the most important factors that should be considered while regulating and monitoring air pollutants in cities and nations is air pollution monitoring [15]. Several studies have been conducted to track the evolution of $NO_2$ in the atmosphere and its changes. The theoretical analysis of the mechanisms by which population size influences pollution is done [16]. However, ongoing land cover changes and a wide variety of aerosol forms make it challenging to identify remote sensing information. Due to its distinctive high-frequency spectrum characteristics in the 400-500 nm wavelength range, $NO_2$ can be seen from space [17]. Tropospheric Monitoring Instrument (TROPOMI) data-based current technical methodologies encompass multiple regional scale studies of both spatial and temporal air pollution dynamic states monitored [18]. The TROPOMI tropospheric vertical $NO_2$ (Nv, trop) columns have a 15%–40% [19] lower bias than comparable in situ measurements [20]. The other factors, besides emissions, that affect the $NO_2$ gradient in the troposphere observed by TROPOMI include local meteorological circumstances and long-range air transport of $NO_2$ [10]. It is documented that the relationship between $NO_2$ atmospheric temperature column intensity and ambient levels, which is seen by satellites, and the majority of surface $NO_2$ is produced by human activity and has a short lifetime [21]. These recently released, highly spatiotemporal-resolution ground $NO_2$ data from satellites are crucial for furthering environmental and health science. Other factors, besides emissions, affect the $NO_2$ level in the atmosphere observed by TROPOMI including local meteorological circumstances and $NO_2$ long-distance air transport [22]. Another study illustrates how EMI may be used for widespread $NO_2$ monitoring and contrasts the commodities OMI and TROPOMI [23]. Utilizing the Google Earth Engine (GEE) platform and the TROPOMI sensor installed on the Sentinel-5P satellite explores the spatiotemporal variability of $NO_2$ [11]. The implications of TROPOMI $NO_2$ satellite-derived for healthcare system experts and regulators who need high-resolution spatial imagery and rapid timelines to monitor, design, and implement legislation [4]. The broad aim of that research is, how effectively the Sentinel-5P satellite images could be used to measure the $NO_2$ instead of ground-based stations to monitor $NO_2$ over a time period in Dhaka and its surrounding districts to detect the seasonal variability and evaluate the factors that are responsible for the level of $NO_2$ concentration. Therefore, this model based on TROPOMI using Sentinel-5P images and GEE platform could be a good solution for taking required initiatives to reduce the $NO_2$ concentration.

## Materials and methods

Bangladesh, a South Asian country consists of 148,460 km$^2$ having over 165 million inhabitants, which is the tenth most populated countries in the world. The greater Dhaka region-Dhaka, Narayanganj, Manikganj, Tangail, Gazipur, Narshingdi, and Munshiganj districts, were selected in this study. The Dhaka district, the highest population in Bangladesh, is located in the center of the country. Dhaka, the capital of Bangladesh, is encircled by a vast metropolitan area known as Greater Dhaka, which is one of the world's megacities with one of the fastest rates of population growth. In addition to being the capital and largest city of the nation, Dhaka's population is also growing as a result of the millions of people who have been displaced from the river delta where they previously lived due to the city's periodic flooding.

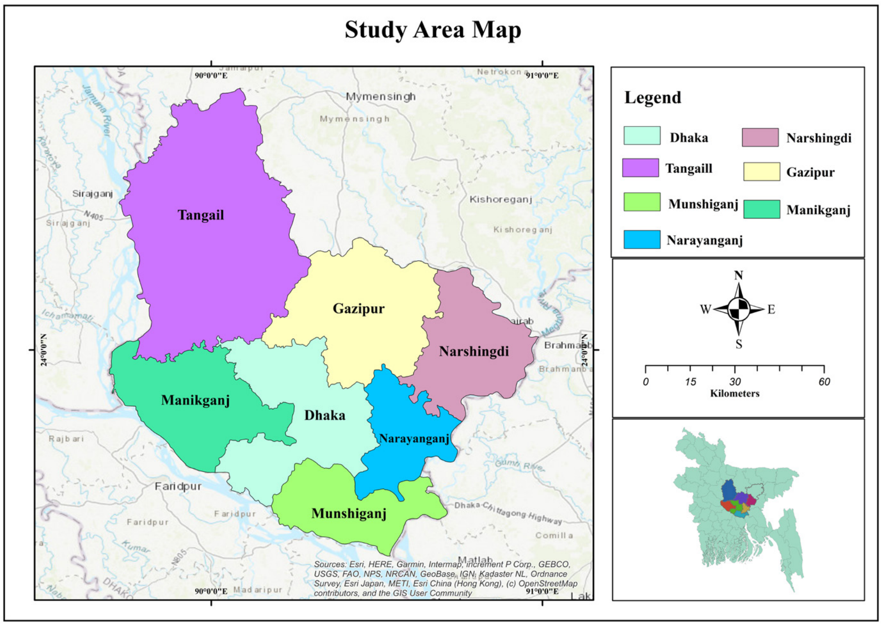


Fig. 1. Geographical location of study area

Table 1. Properties of datasets used in this study

| Name | Dataset provider | Dataset availability | Unit |
|---|---|---|---|
| Sentinel-5P OFFL $NO_2$: offline nitrogen dioxide | European Union/ESA/Copernicus | 2018 to Present | $Mol/m^2$ |
| Population density | European commission/ global human settlement layer | 1975 to Present | Person/ $km^2$ |
| Land use land cover | Esri | 2017-2021 | $Km^2$ |

### *Data acquisition*

This study is mainly based on the secondary data source -satellite images. The purpose of this study is to accomplish the analysis using the TROPOMI datasets from December 2018 to November 2022, Population Density in 2020, and Land Use Land Cover (LULC) from 2019 to 2021.

### *Data processing*

The European Space Agency deployed a satellite called Sentinel-5 precursor on October 13th, 2017 to keep tabs on atmospheric pollution. TROPOMI is a popular name for the sensor installed on board. Except for $CH_4$, all of the S5P datasets can be retrieved in both Near Real-Time (NRTI) and Offline formats (OFFL). Only OFFL is a source of $CH_4$. Despite being more condensed in scope than OFFL's holdings, the NRTI assets show up sooner after being purchased. The OFFL archives only provide information from one rotation. The only situations in which it would be wise to apply a filter to these numbers would be for extremes, such as vertical columns below -0.001 mol/m2. Sentinel 5P Level 2 (L2) initially, time intervals were used to categorize data instead of geographic coordinates. Each Sentinel 5P L2 material is altered to L3, maintaining a single grid in each orbit, so that the data can be consumed by Earth Engine. To get the intended outcome in this study, we leverage the tropospheric $NO_2$ column number density as a band attribute and analyze it on the Google earth platform.

The TROPOMI detector on board the S5P satellite has rapidly evolved into one of the most prominent sensors for evaluating atmospheric pollution [11]. Total amounts of L2-$NO_2$ products were applied to generate the daily atmospheric temperature $NO_2$ column density, a step up in processing from Level 2 [18]. It contains four spectrometers which encompass the UV, VIS, NIR, and SWIR using 7 bands. The 405–500 nm spectral region of the fourth band, can be utilized to evaluate $NO_2$. It has a superior spatial, temporal, and spectral resolution to any other sensors ever deployed [11]. In centralized control systems, process data is collected locally at the controllers and then sent to the control center, where it is processed by the intelligent building. Conventional values obtained and digital variable states are common types of process data. The SENTINEL-2p and SENTINEL-5p data from four years were used in this investigation (December 2018 to November 2022). The "Google Earth Engine" has greater precision of these data for download. In addition to the images, a "CSV" file was retrieved from there. The daily $NO_2$ concentration data obtained from the "CSC" file. The existing scenario in Greater Dhaka by estimating the Maximum, Minimum, Mean, and Standard Deviation of $NO_2$ concentration.

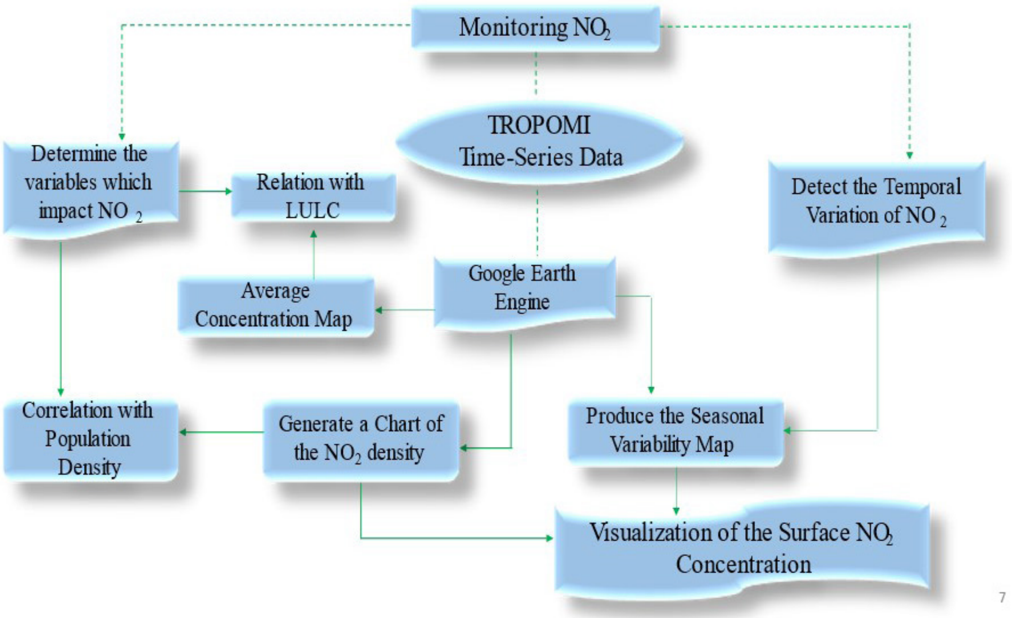


Fig. 2. The methodological framework of this study

Table 2. Statistical values of $NO_2$ in 2018 December to 2022 November

| Month | December | January | February | March | April | May | June | July | August | September | October | November |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Max | 2.38 | 2.49 | 2.49 | 3.18 | 1.95 | 1.91 | 1.86 | 1.55 | 1.7 | 2.48 | 2.4 | 2.3 |
| Min | 0.67 | 0.71 | 0.77 | 0.82 | 0.74 | 0.47 | 0.7 | 0.58 | 0.63 | 0.6 | 0.62 | 0.6 |
| Mean | 1.29 | 1.41 | 1.44 | 1.46 | 1.18 | 1.16 | 1.11 | 1.05 | 1.07 | 1.2 | 1.24 | 1.09 |
| STD | 0.32 | 0.36 | 0.37 | 0.44 | 0.23 | 0.28 | 0.23 | 0.23 | 0.24 | 0.33 | 0.30 | 0.32 |

## Results and discussion

Since $NO_2$ is a pollutant that is detrimental to the environment, keeping a close eye on its content is critical. The ultimate priority of this analysis is to track the $NO_2$ concentration in Greater Dhaka from 2018 to 2022. Numerous factors contribute to the rise in $NO_2$. The scientific findings demonstrate how $NO_2$ concentration varies seasonally and strongly influence raising $NO_2$ levels. Additionally, this research has looked into these difficulties.

There is a distinct seasonal pattern present. Peak $NO_2$ is substantially greater in the winter. The increased use of ignition reactors for wintertime domestic heating and the reality that $NO_2$ lingers in the atmosphere longer throughout the winter is to blame for this. Photochemical processes mostly influence $NO_2$ atmospheric lifespan. Because there is less sunshine in the winter, processes that deteriorate $NO_2$ are more difficult to start and are expelled from the atmosphere more gradually.

Considering four years in the greater Dhaka regions, the season was segmented into four sectors and assessed the four-season value in terms of maximum, minimum, mean, and standard deviation.

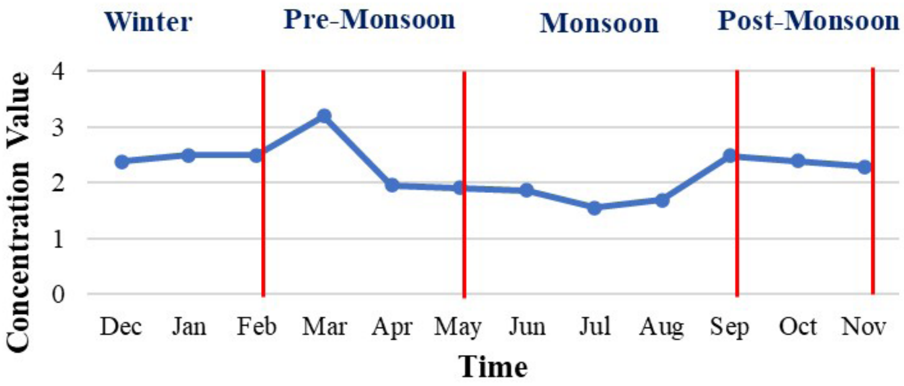


Fig. 3. Maximum Concentration of $NO_2$ according to the different season

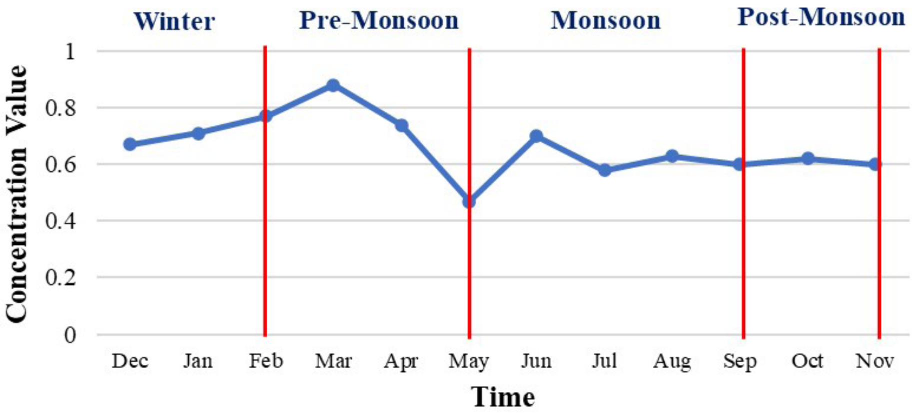


Fig. 4. Minimum Concentration of $NO_2$ according to the different season

Following the graph, it is feasible to observe that the highest concentration level consistently exceeds $1.5*10^{-4}$ mol/m$^2$, on average. The concentration values, in contrast, continue to be higher than $3*10^{-4}$ mol/m$^2$ during the pre-monsoon season. The real state of maximum concentration in the ensuing years is depicted in this single graph. We can discern a pattern that shows the concentration level is highest in the winter, gradually declines in the summer, and then rises once more in the post-monsoon season.

The minimal concentration value is depicted in the above graphical representation. The minimum concentration value continues on average lower $1*10^{-4}$ mol/m$^2$. But through the winter season, the concentration level is higher than in other seasons. In 2020, the concentration value remained the lowest.

This composite graph illustrates the actual minimum concentration state throughout the following years. The concentration level of the lowest value is highest in the winter, diminishes in the summer, and then gradually increases again during the post-monsoon season, according to an apparent regularity.

The average $NO_2$ concentration is illustrated in the graphs above. The mean concentration fluctuates from 0.95 to 1.8, with 1.8 being the highest value.

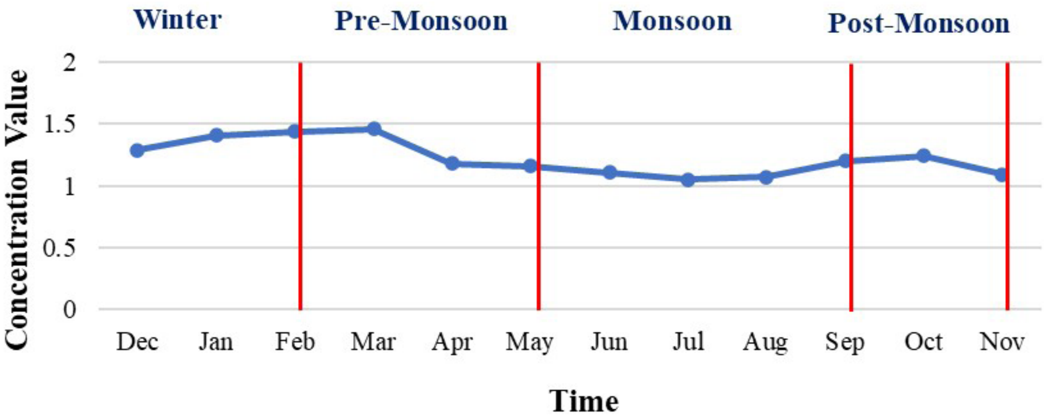


Fig. 5. Mean Concentration of $NO_2$ according to the different season

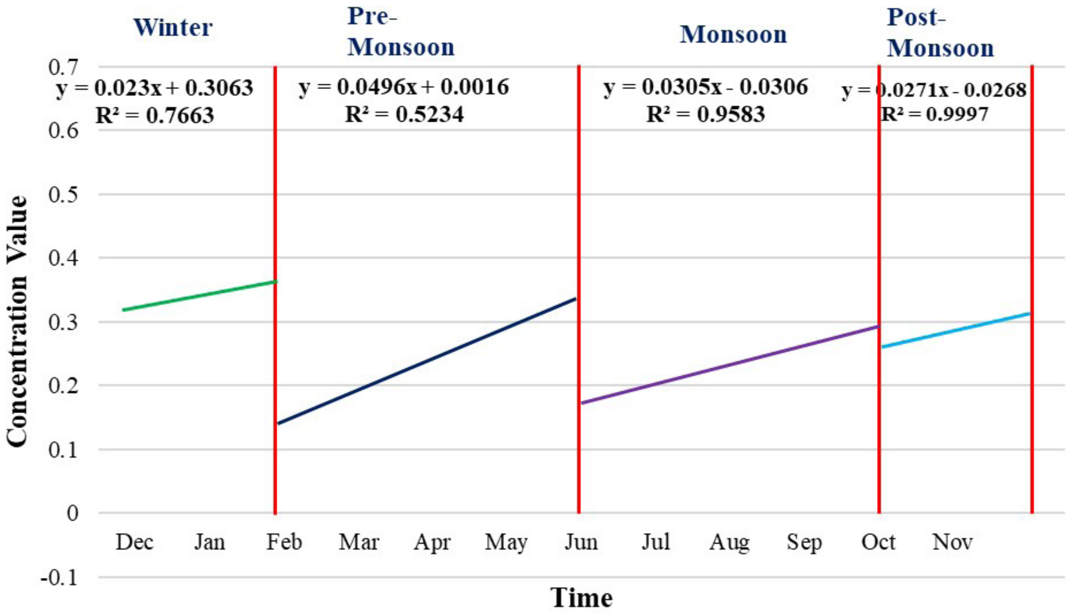


Fig. 6. Trendline of $NO_2$ concentration according to the different season

The mean value is highest during the winter season, and remains lower during the pre-monsoon and monsoon seasons. Because $NO_2$ can only be broken down in bright light, the pre-monsoon and monsoon seasons are characterized by bright light, which ensures that the concentration of $NO_2$ is maintained at a low level during both times.

The trendline displays the rising trend of the $NO_2$ concentration about the standard deviation value. Looking at the $R^2$ value through the uptrend lines, the pre-monsoon season has the lowest value (0.5234), while the post-monsoon season has the highest value (0.9997). This factor determines the level of $NO_2$ concentration. If the $R^2$ value goes up, the $NO_2$ level will also go up. On the other hand, if the $R^2$ value goes down, then the $NO_2$ concentration will also go down.

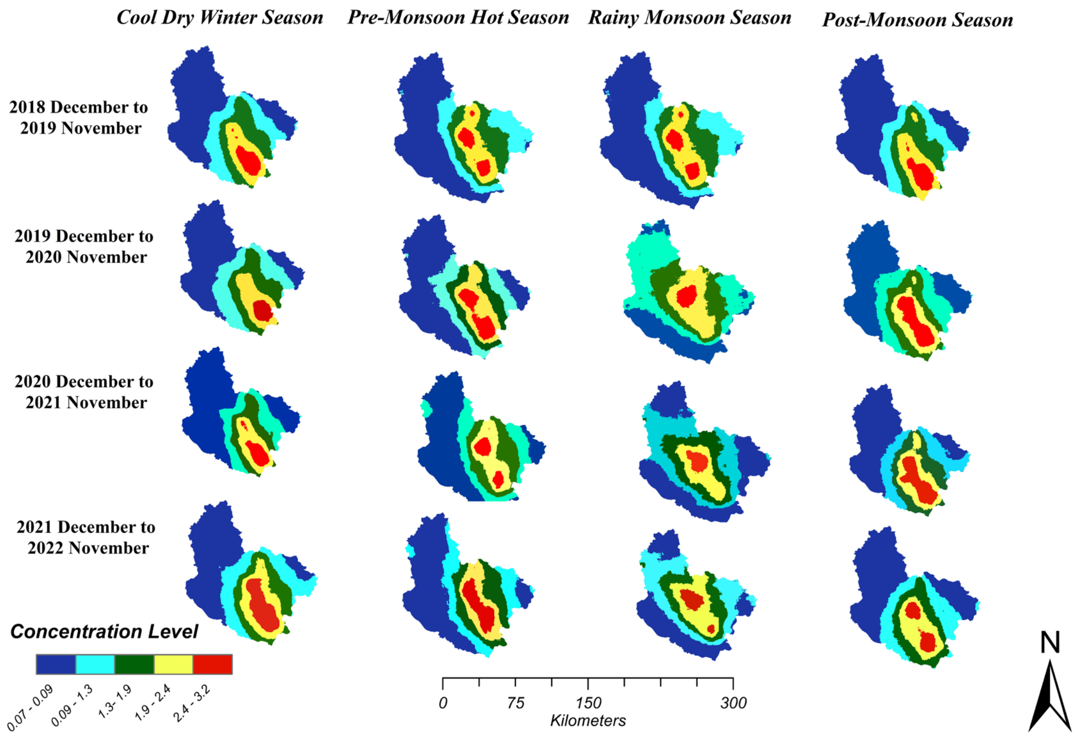


Fig. 7. Concentration Map of $NO_2$ according to the different season

The above map shows the seasonal variability of Greater Dhaka from December 2018 to November 2022. When the level of $NO_2$ in the atmosphere in a city rises above the threshold established by environmental factors, an occurrence event is notified. The occurrence of this phenomenon is primarily confined to the winter season. Largely, photochemical reactions determine how long $NO_2$ stays in the atmosphere. Since there is less radiation in the winter, it takes longer for the mechanisms that disintegrate $NO_2$ to get started, and hence longer for the $NO_2$ to be eliminated from the atmosphere. From the map (Fig. 7), we can visualize that that the concentration level is higher in the winter season than in other seasons. Day by day the $NO_2$ concentration level is increasing dramatically.

There are numerous contributing factors to the rise in $NO_2$. The following study examines how population density and LULC vary as a function of $NO_2$ and how these factors affect $NO_2$ concentration. Reduced combustion rates lead to lower $NO_2$ concentrations in densely inhabited areas. The results indicate a modestly positive relationship (r=0.52) between population density and $NO_2$. Pearson's correlation coefficient can assume values between -1 and +1. A negative correlation indicates a result near -1, whereas a positive correlation indicates a result close to +1. The characteristics in the subsequent study are highly correlated with one another. Therefore, the $NO_2$ concentration rises as the population increases and falls as the population decreases. The Greater Dhaka region is the most populous part of Bangladesh. Most of Dhaka and the district of Narayanganj have very high population densities, and thus very high $NO_2$ concentrations. The tremendous growth of humanity, the escalation of human activities, and the failure to properly plan for urban development have all contributed to a global decline in environmental quality, particularly in cities.

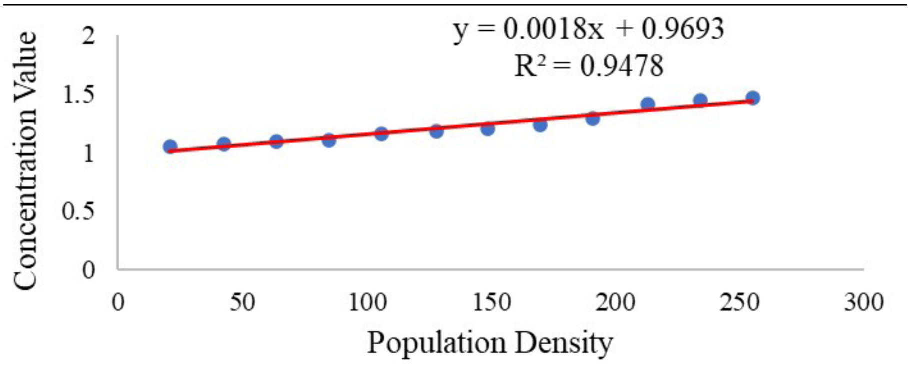


Fig. 8. Pearson correlation coefficient

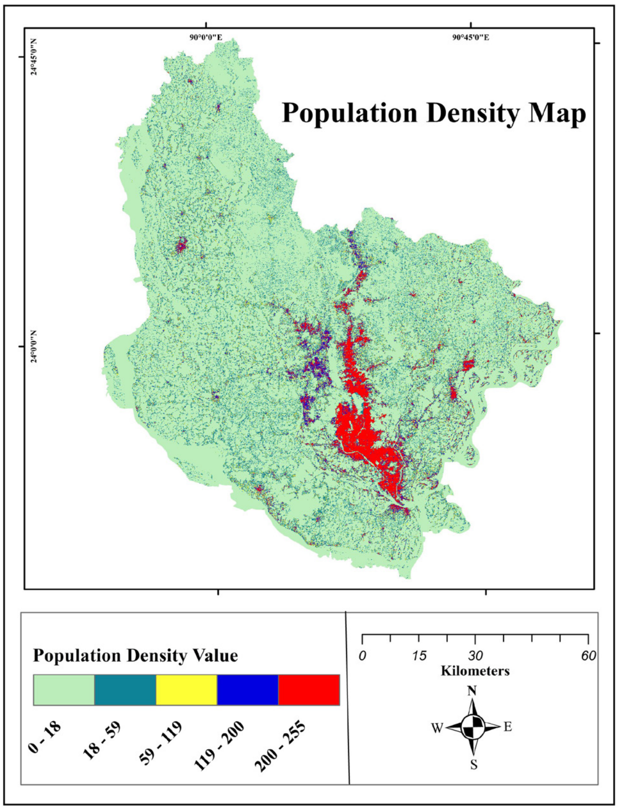
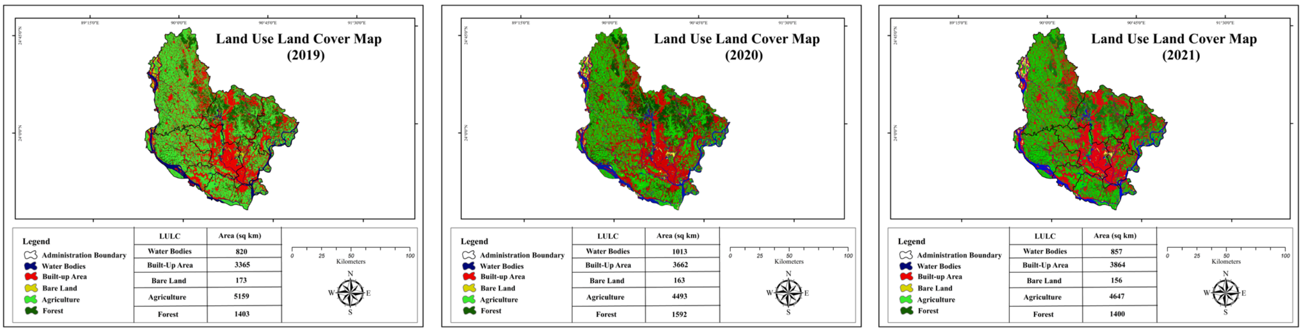


Fig. 9. Population density map

This graph illustrates the strong positive relationship between $NO_2$ levels and population density. The outcome indicates population densities highly alter the concentration of $NO_2$. On the other hand, the subsequent map also supports this assertion. The following map (Fig. 9) shows the density of population dispersion in greater Dhaka, and the other image shows the average level of $NO_2$ in the atmosphere. Both maps show that regions with high densities, such as urbanized areas, contain high concentrations. On the other hand, low concentration levels were seen in rural areas. It can extrapolate from findings mentioned above that population density and concentrations have a tangible link.

The LULC forms, a dominant driver of all boundary layer exchanges, affecting the energy balance of the Earth and the rates at which air pollutants are emitted and settled to the ground. Given that most LULC effects on biological and chemical processes originate in the atmosphere, the first step in evaluating air quality is to examine how LULC is distributed. There is more proof of increased $NO_2$ concentrations in metropolitan areas, with more emissions and emphasis placed on the regional allocation of these emissions. The following tables show the gradual increase in the built-up area and the concentration level. Even though the population density dropped during the lockdown, the urban sprawl grew. Here we can observe the diverse scenarios that year.

These maps illustrate that the areas with the highest population density, such as Dhaka and Narayanganj, have the highest concentration levels. Built-up regions can produce and emit a wide range of contamination, the most noticeable of which are waste material, and dust. Unfortunately, development and construction regions also emit less evident hazardous contaminants for human health and impact on the ecosystem. These pollutants are a cause for great concern. $NO_2$ is produced on construction and demolition sites by engines that are fueled by diesel or gasoline. These engines are found in heavy-duty trucks, construction equipment, mobile cranes, and other off-road machinery. Deterministic vehicles such as impellers and power generation also contribute to the production of $NO_2$. The urbanization level of Dhaka and Narayanganj is higher than that of other regions of the greater Dhaka area. The built-up area had a significant amount of the substance. During 2019, the greater Dhaka engulfed a substantial portion of the built-up area. In addition, there is a greater abundance of vegetation and a decreased prevalence of arid regions. Dhaka's metropolitan area has a high concentration of urban areas and farmland due to the low percentage of water bodies in the territory. Nearly 47% of the land is used for agricultural purposes, while the remaining 31% is built up. In addition, this region contains 13% forest, 7% water bodies, and only tiny part of the uncultivated ground (2%).



| LULC | Area (sq km) |
|---|---|
| Water Bodies | 820 |
| Built-Up Area | 3365 |
| Bare Land | 173 |
| Agriculture | 5159 |
| Forest | 1403 |

| LULC | Area (sq km) |
|---|---|
| Water Bodies | 1013 |
| Built-Up Area | 3662 |
| Bare Land | 163 |
| Agriculture | 4493 |
| Forest | 1592 |

| LULC | Area (sq km) |
|---|---|
| Water Bodies | 857 |
| Built-Up Area | 3864 |
| Bare Land | 156 |
| Agriculture | 4647 |
| Forest | 1400 |

Fig. 10. Land Use Land Cover Map of Greater Dhaka, 2019 to 2021

Table 3. Land Use and Land Cover in 2019

| LULC | Area (km$^2$) | Percentage (%) |
|---|---|---|
| Water Bodies | 820 | 7 |
| Built-Up Area | 3365 | 31 |
| Bare Land | 173 | 2 |
| Agriculture | 5159 | 47 |
| Forest | 1403 | 13 |

Table 4. Land Use and Land Cover in 2020

| LULC | Area(km$^2$) | Percentage (%) |
|---|---|---|
| Water Bodies | 1012.906 | 9 |
| Built-up | 3661.939 | 34 |
| Bare Land | 163.6814 | 1 |
| Agricultural Land | 4493.089 | 41 |
| Forest | 1592.036 | 15 |

Table 5. Land Use and Land Cover in 2021

| LULC (2021) | Area (km$^2$) | Percentage (%) |
|---|---|---|
| Water Bodies | 856.7336 | 8 |
| Built-up Area | 3863.857 | 35 |
| Bare Land | 155.9029 | 1 |
| Agriculture | 4647.313 | 43 |
| Forest | 1399.85 | 13 |

In 2020, the greater Dhaka encompassed a large percentage of the region that had been built upon. The built-up area has seen an additional 3% growth compared to the previous years. In addition to this frightening trend, the amount of land suitable for agricultural use has decreased by about 6%. This scenario affects the growth in the concentration of $NO_2$ in the atmosphere.

The amount of land covered by buildings in the greater Dhaka area has increased each year, while at the same time, other aspects of the environment have shrunk. Combustion is a significant contributor to the formation of $NO_2$ concentration, and built-up areas, along with their associated buildings, industrial zones, and road networks, are all significant contributors. The concentration level rises to meet the demands of the situation to the extent that the built-up area grows.

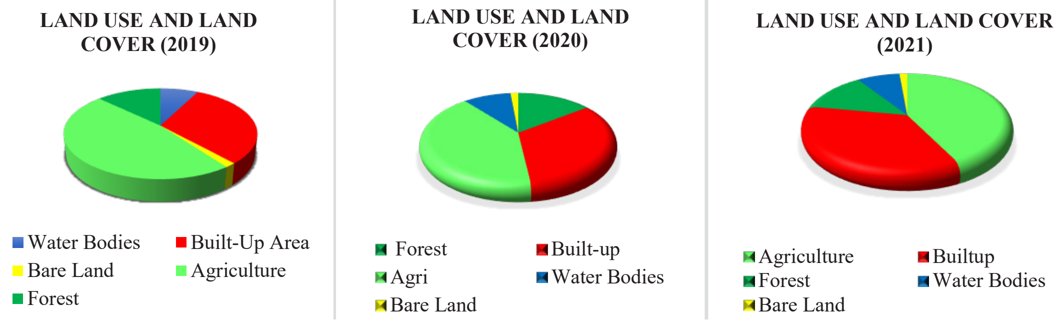


Fig. 11. LULC Distribution in different years

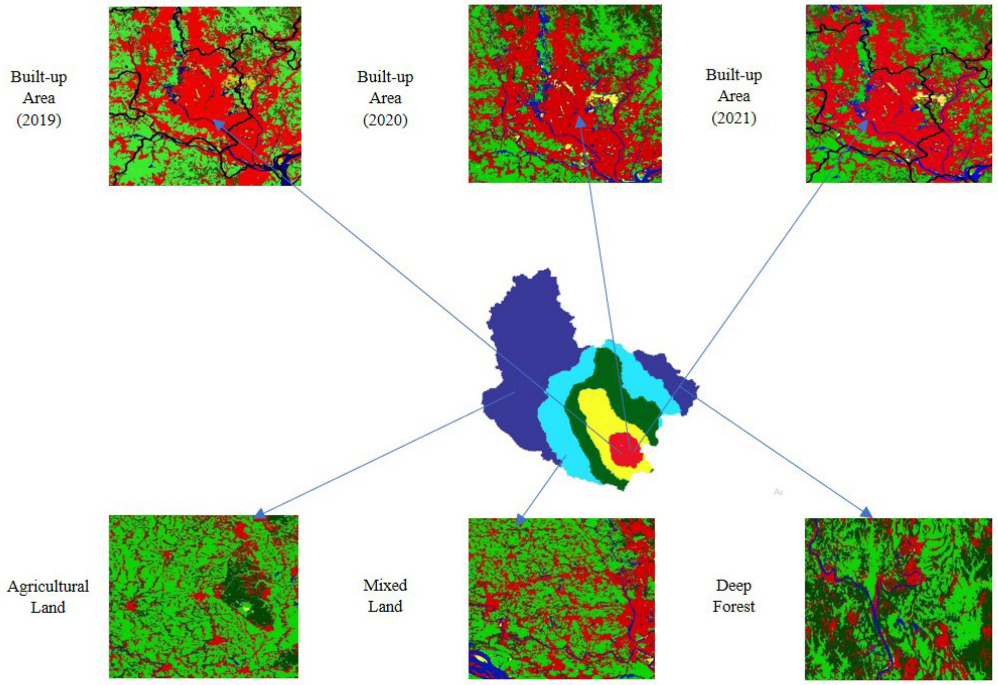


Fig. 12. Relationship among the land use properties with the concentration level

The troposphere and stratosphere contain $NO_2$, a significant trace gas in the Earth's atmosphere. Indirectly or directly, $NO_2$, one of the most prevalent tropospheric pollutants, harms human health. As problems with air quality occur frequently in both time and space, they are a spatiotemporal phenomenon. Numerous factors can affect where and how much $NO_2$ is present at any one time. The airways of the human respiratory system may get irritated when breathing air with a high $NO_2$ concentration. Such brief exposures have been shown to potentially exacerbate respiratory diseases like asthma. On the other hand, when $NO_2$ combines with airborne particles including oxygen, water, and other compounds, acid rain is created. Lakes, woods, and other delicate ecosystems suffer damage from acid rain. High quantities of nitrogen dioxide harm leaves, slow growth, or diminish crop yields, which negatively effects on vegetation. $NO_2$ exhibited seasonal variations. $NO_2$ monitoring, which helps measure the amount of $NO_2$ we breathe in and warns us when a specific level is surpassed, is an effective technique to stop the accumulation of high amounts of $NO_2$. When creating an action plan to achieve criteria and computing the air quality index to give health advisories, real-time monitoring of $NO_2$ levels is helpful. The findings showed that the concentration level steadily increases in the winter and decreases in the summer and monsoon seasons. The population density and land use land cover of a region affect the level of $NO_2$ concentration. High concentration levels are maintained in areas with high population densities, and these levels are also present in built-up areas. Attributed to the reason that $NO_2$ typically occurs in the same environment as particles and it is problematic to isolate the relative contributions of the mixture's various components, the toxicity or health impacts related to exposure to $NO_2$ have been contested.

The harmful consequences on people's health. Even though industrial pollution has declined over the past two decades due to technological advancements and the restructuring or modernization of power plants, the situation concerning $NO_2$ pollution is still complicated. It's important to note that traffic-related pollution is still rising as the number of vehicles increases. By reacting with other compounds frequently present in the air, nitrogen oxides are swiftly decomposed in the environment. Nitric acid, a key component of acid rain, is generated due to the reaction between nitrogen dioxide and molecules from sunlight. Additionally, when sunshine and nitrogen dioxide combine, ozone and smog conditions are created in our breathe. For this reason, monitoring the $NO_2$ level is necessary because it’s a significant element for humans and the environment.

## Conclusion

$NO_2$ is a gas that is produced as a byproduct of combustion activities. At high temperatures, around eighty percent of the nitrogen in the air is transformed into nitrogen monoxide, and some of it is also changed to nitrogen dioxide. The tropospheric column $NO_2$ intensity from 2018 to 2022 was analyzed with aiming to monitor Dhaka and its surrounding areas to detect temporal changes with the TROPOMI sensor data. We divided these years into seasonal patterns to detect the temporal variation from 2018 to 2022. This can visualize the seasonal variability and detect the high and low levels of $NO_2$ in the study area. Spring, summer, winter, and fall are the four seasons. Each season lasts roughly three months and corresponds to a time of the year when the climate and temperature are comparatively stable. Nitrogen dioxide in the atmosphere is immediately oxidized and transformed into nitrate aerosols, a prominent particulate matter source and $NO_2$ can perform as an O3 precursor. Through the graph, we can analyze the variability and connectivity of the concentration of $NO_2$ significant link between levels of $NO_2$ and population density. If more people live in the same space, will be more $NO_2$ produced. On the other hand, the amount of $NO_2$ in the air will go down if fewer people are living in an area. The built-up area affects the concentration level of $NO_2$. The level of concentration gradually reaches an extremely high point. The maximum $NO_2$ concentrations are in the most densely populated and developed regions. As $NO_2$ species are formed while burning of fuels, it can be leveraged to determine the amount of radiation generated by fossil fuels in addition to the founder's greenhouse gases and other pollutants. This is possible because $NO_2$ species are created due to the combustion processes. Numerous investigations have been carried out during the recent two decades to look into the use of remote sensing in monitoring $NO_2$ pollution. Considering the significance of observing contaminants like $NO_2$, little research has been done to investigate changes in space and time. This study intended to explore the current state of $NO_2$ concentration in Dhaka and the areas that surrounding the city, as well as to establish the factors that influence $NO_2$ levels. There is still a high concentration during the winter season, but reduced concentration is seen during the wet season. Because Dhaka and Narayanganj are the areas of greater Dhaka with the highest population density and concentration of industries, those areas have exceptionally high levels of $NO_2$ concentration.

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This research received no external funding.

### Competing interests

The authors declare no conflict of interest.

### Author’s contributions

Conceptualization, R.R.; methodology, R.R. and N.S.; software, N.S. and S.H.; validation, N.S. and S.H.; formal analysis, N.S.; investigation, S.H.; resources, N.S.; data curation, S.H.; writing—original draft preparation, N.S. and S.H.; writing—review and editing, R.R.; visualization, N.S. and S.H.; supervision, R.R. All authors have read and agreed to the published version of the manuscript.

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### Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors.

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