Affecting Factors NO_2 Distribution between 2019-2021 in the East Java, Indonesia

ABSTRACT

Studies were conducted in East Java over a span of three years, covering the pre-pandemic, during pandemic, and post Covid-19 pandemic. Studies were conducted in East Java over a span of three years, covering the pre-pandemic, during pandemic, and post Covid-19 pandemic. The articel present NO_2 consentrations based on geoinformation research methods that utilize sentinel-5P TROPOMI satellite imagery with the cloud computing platform Google Earth Engine (GEE) and Quantum GIS-LTR 3.34.15 software. Supporting data on this article on industrial, population growth, and transportation activities is sourced from Statistics Indonesia. The result show that areas with high industrial and transportation activities such as Gresik, Surabaya, and Probolinggo have higher concentration of NO_2 than other areas. The concentration of NO_2 still below the threshold set by Meteorology, Climatology, and Geophysical Agency, altough urban areas show a higher risk of NO_2 pollution. The conclusion of this study confirmed the importance of monitoring spatial-based air quality to support effectiveness of environmental manegement policies. Reduction of NO_2 emissions during the pandemic Covid-19 indicate that industrial and transportation activity is the main contributed factor to NO_2 pollution. Mitigation strategies such as using green technologies and developt of sustainable transportation system are needed to reduce NO_2 emission in the future.

***Key word**: nitrogen dioxide (NO_2), air quality, COVID-19 pandemic, sentinel-5P, Google Earth Engine*

1. INTRODUCTION

Air is a vital element of human, animal, and plant life. However, in this modern era, the rapid development of urban development, industrial centers and transportation has brought significant changes to air quality (Della Ertiana, 2022). This change is largely due to air pollution, the introduction of gas or small particles (aerosols) into the atmosphere for a considerable amount of time. This condition can negatively affect human health, animal welfare, and plant survival, while threatening the overall ecosystem balance. Long-term exposure to air pollutants such as NOx, CO_2, SO_2, and particulates can cause serious damage to the respiratory and cardiovascular systems, as well as increase the risk of premature death (Hasan et al., 2020).

East Java, as one of the provinces with high economic activity in Indonesia, faces significant challenges in air pollution management. The economy of East Java in 2022 grew by 5.34% with growth in almost all business fields except mining and excavation. Transportation and warehousing (Izza et al, 2023) have significant growth. The rapid growth of urbanization and industrialization in the region has affected air quality. Nitrogen dioxide (NO_2), which is one of the major air pollutants produced from human activity, is an indicator of air pollution (Zhang et al, 2023). Long-term exposure to NO_2 can cause serious respiratory problems and increase the risk of chronic disease. In addition, the long-term impact of NO_2 is the damage to the stratospheric ozone layer which increases UV radiation leading to an increase in skin cancer incidence (Vries, 2021).

Therefore, a comprehensive analysis is required to understand the distribution patterns and trends in NO_2 concentration to support data-based decision making. The 2019–2021 timeframe was chosen to provide a comprehensive picture of the pattern and trend of NO_2 concentration in East Java. In addition, this period includes the dynamics of human activity before and during the COVID-19 pandemic, which affects emission patterns in various sectors. Analysis in this time range is also important to evaluate the effectiveness of air pollution control policies that have been implemented and provide a view for future mitigation planning.

According to those conditions, the study aims to analyze the spatial and temporal distribution patterns of NO_2 in East Java during the 2019–2021 period, as well as identify major factors affecting its concentration. This study uses Google Earth Engine, a cloud-based platform that enables high-efficiency analysis of geospatial data. Sentinel-5 Precursor also known as Sentinel-5P is the first Copernicus mission dedicated to monitoring our atmosphere. The satellite carries the state-of-the-art Tropomi instrument to map a multitude of trace gases such as nitrogen dioxide, ozone, formaldehyde, sulphur dioxide, methane, carbon monoxide and aerosols all of which affect the air we breathe and therefore our health, and our climate (European Space Agency, 2017). The results of this analysis are expected to contribute to the development of more effective air quality management strategies at regional and national levels.

2. MATERIAL AND METHODS

2.1 Data

Table 1. Data Source and descriptions

Data Layer	***Source***	***Spatial Resolution (meter)***	***Date***
Sentinel-5P NRTI NO_2 (Near Real-Time Nitrogen Dioxide)	*European Union/ESA/Copernicus*	*1:10*	*2019,2020,2021*

This study used NO_2 concentration data from Sentinel-5P satellite imagery with Tropomi or "Tropospheric Monitoring Instrument" sensors. The data sets used in this study used versions of Near Real-Time or NRTI. Sentinel-5P features a spectrometer called the Tropospheric Monitoring Instrument (TROPOMI). TROPOMI is useful for measuring UV-visible wavelengths (270–500 nm), near infrared (710–770 nm), and shortwave infrared (2314–2382 nm). TROPOMI has a spatial resolution of 7 x 3.5 km2 for 2-6 (UVN), 7 x 7 km2 for 7 and 8 (SWIR) bands, and 21 x 28 km2 for 1 (deep UV). With this resolution, TROPOMI has advantages over its predecessors such as OMI (Ozone Monitoring Instrument), SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) and GOME-2 (Global Ozone Monitoring Experiment-2). In addition, this study also used data on population growth in East Java, the distribution of NO_2 in East Java, the distribution of industry in East Java, and the use of transportation in East Java obtained from the Statistics Indonesia.

2.2 Data Processing

The distribution data of NO_2 used in this article is distribution of NO_2 conditions throughout 2019, 2020, and 2021. The condition in the three years is expected to describe the pre-COVID-19 pandemic condition, during the COVID-19 pandemic, and after the COVID-19 pandemic. This study compared three NO_2 distribution conditions using Google Earth Engine in each year to look at the trend of NO_2 distribution. The following command is used to generate NO_2 distribution:

```
var collection = ee.ImageCollection('COPERNICUS/S5P/NRTI/L3_NO2')
  .select('NO2_column_number_density')
  .filterDate('2019-06-01', '2019-06-06');

var band_viz = {
  min: 0,
  max: 0.0002,
  palette: ['black', 'blue', 'purple', 'cyan', 'green', 'yellow', 'red']
};
```

```
Map.addLayer(collection.mean(), band_viz, 'S5P N02');
Map.setCenter(65.27, 24.11, 4);
```

After displaying the NO_2 distribution, the next step is to present the graphic parameters and generate the graphic using the following command:

```
// script parameter grafik
var options = {
 title: 'Grafik Kadar No2 Tahun 2021',
 hAxis: {title: 'Bulan ke-'},
 vAxis: {title: 'Kandungan NO2'},
 lineWidth: 1,
 pointSize: 4,
 };

var waktu = [1, 2, 3, 4,5,6,7,8,9,10,11,12];

// Script memunculkan grafik
var chart = ui.Chart.image.regions(
  stacked_composite, geometry, ee.Reducer.mean(), 30, 'label', waktu)
   .setChartType('ScatterChart')
   .setOptions(options);

// Display grafik.
print(chart);
```

After displaying the NO_2 distribution image, the parameters, and graphic data are downloaded and described according to the discussion. The distribution of NO_2 emission maps are digitized using Google Earth Engine historical emagery between 2019-2021 and imported into Quantum GIS for analysis and layouting. The historical imagery data collected from various time.

3. RESULTS AND DISCUSSION

3.1 Analysis of NO_2 Concentration Changes from 2019-2021

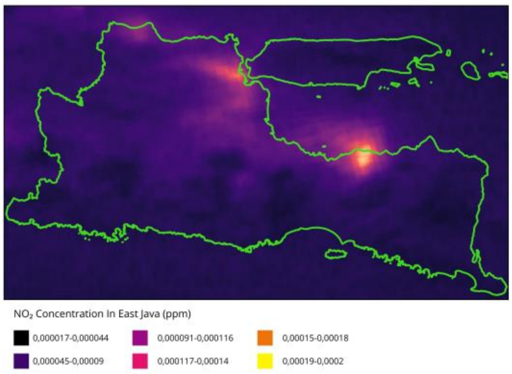

Figure 1. NO2 Concentration In East Java 2019

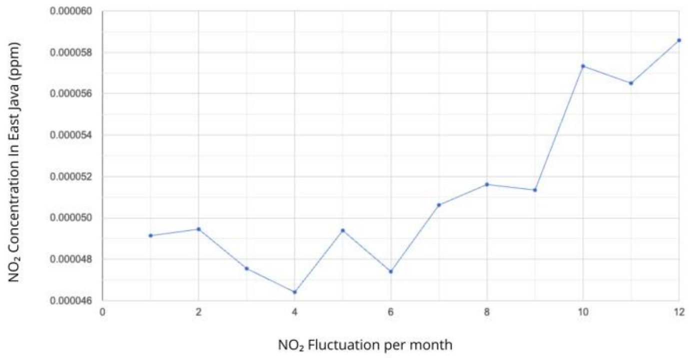

Fig 2. NO2 Fluctuation In East Java 2019

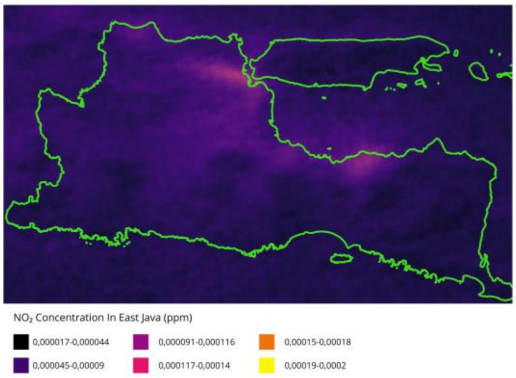

Figure 3. NO2 Concentration In East Java 2020

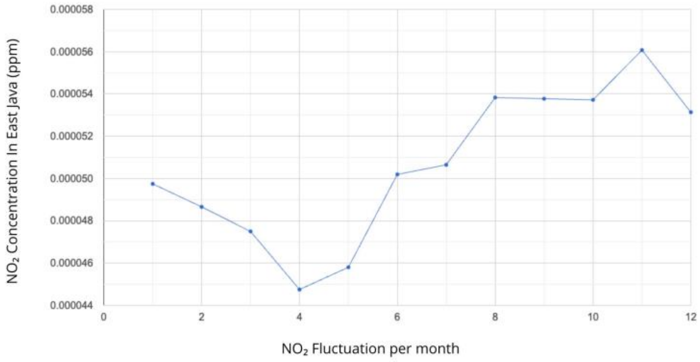

Fig 4. NO2 Fluctuation In East Java 2020

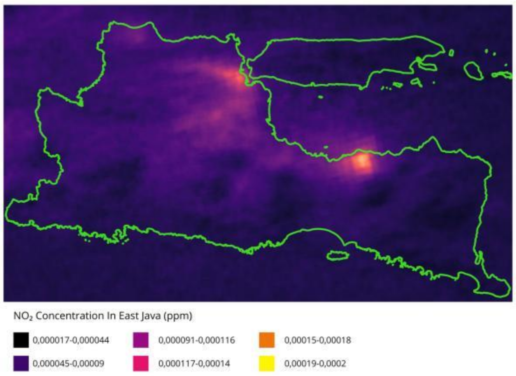

Figure 5. NO2 Concentration In East Java 2021

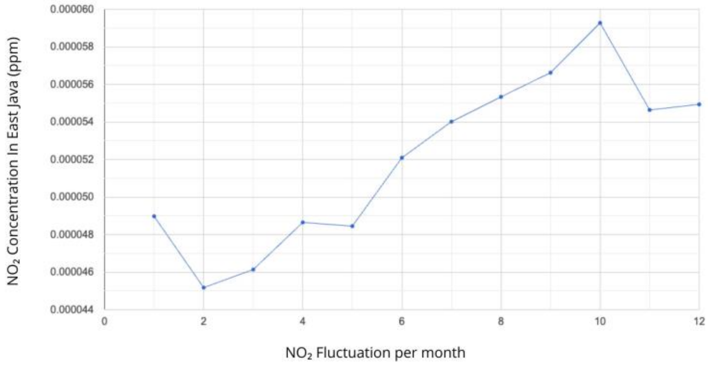

Fig 6. NO2 Fluctuation In East Java 2021

The standard value of nitrogen dioxide pollution based on the Meteorology, Climatology, and Geophysics Agency is 0.08 ppm. Based on the trend chart of NO_2 distribution from 2019 to 2021, it has generally not yet reached the quality standards set by the Meteorology, Climatology, and Geophysical Agency. The highest value of distribution for three years is 0.000059 ppm in 2019 which indicates that the distribution of NO_2 in East Java is still safe for the environment and health. Meanwhile, the lowest value for three years reached 0.000045 ppm in 2020 and 2021. The NO_2 distribution values from 2019 to 2021 exhibit a similar trend, with a decline in the first few months of the year, followed by a sharp increase starting in the sixth month and continuing until the end of the year. This indicates that there are repeated activities in the East Java area, including industry, transportation, and other NO_2 producing activities. During the COVID-19 pandemic, the value of NO_2 distribution is also not too far different from the pre- and post-pandemic periods, indicating that NO_2 generating activities are still running even though they are limited to the pandemic period.

The highest value of NO_2 contamination in East Java is described in bright yellow to red in the Gresik, Surabaya, and Probolinggo regions. The three regions are the regions with the highest NO_2 distribution in East Java. As in the research by Zulkarnain and Ramadani (2020), there are several NO_2 hotspots in Java, namely Jabodetabek, Cilegon City, and East Java, namely Surabaya City, Gresik Regency, and Probolinggo Regency. This is influenced by industrial activities located in all three areas. The study conducted by Putra (2020) said that there is a tendency that gas concentration is relatively high in industrial zones, which shows the contribution of gases from industrial business activities, especially in several seasonal winds.

Paiton area, Probolinggo Regency is an area that has Steam Power Plant, causing NO_2 pollution to the environment. Seen from the image of NO_2 distribution, the Paiton area has bright yellow and red colors indicating the high value of NO_2 even though it is still quite far from the quality standards set by Meteorology, Climatology, and Geophysics Agency. Other PLTU activities such as loading and unloading of materials are also a fa ctor in the occurrence of air pollution. A study by Bahri (2018), stated that there is a dominant particulate matter that has an effect on respiratory distress, both from the coal loading and unloading process, so that this coal loading and unloading activity causes respiratory distress.

3.2 Factors Affecting Changes in NO_2 Concentration

Changes in the concentration of NO_2 are influenced by various factors associated with anthropogenic human activity, geographical conditions, and weather patterns. On a global scale, emissions of nitrogen oxides from natural sources far outweigh those generated by human activity. Natural sources include intrusion of stratospheric nitrogen oxides, bacterial and volcanic action, and lightning. However, because natural emissions are distributed over the entire surface of the earth, the resulting background atmospheric concentrations are very small. The major sources of anthropogenic emissions of nitrogen oxides into the atmosphere are the combustion processes in stationary sources (heating, power generation) and in mobile sources (internal combustion engines in vehicles and ships) (WHO, 2005).

Based on the results of analysis, the change in the concentration of NO_2 in East Java province showed that the Gresik, Surabaya and Probolinggo regions experienced the highest NO_2 contamination. These conditions indicate that anthropogenic factors have a significant influence in contributing NO_2 contamination because the three regions are urban centers, industrial centers and PLTU locations. The following describes how anthropogenic factors affect changes in the concentration of NO_2 in East Java province.

3.2.1 Industrial Activities

Statistics Indonesia (East Java Province) reported that in 2021 there were 5,782 large medium-sized industrial companies active in the East Java region. The criterion for a medium-sized industry is having between 20 and 99 employees, while a large industry is defined as having at least 100 employees. Some industries use fossil fuels in their operations without adequate emission control, often resulting in the release of pollutant gases, including NO_2. The condition of many industrial areas in East Java causes this concentration of pollutants to increase, especially in areas with dense industrial activity. According to Statistics Indonesia (East Java Province) data, the most densely populated areas are Sidoarjo (772-1106 companies), followed by Surabaya, Gresik and Pasuruan (319-771 companies).

The data on the number of industries supports the results of the NO_2 distribution map analysis, which shows high NO_2 concentrations in areas such as Surabaya and Gresik. Industries in Surabaya have been shown to contribute to the distribution of pollutants, particularly SO_2 and NO_2, which are then carried by the wind and influenced by wind direction in industrial areas (Suwanto and Kusuma, 2023). Satellite image analysis results indicate that NO_2 emissions in Surabaya City are higher than in Sidoarjo Regency, despite Sidoarjo being the most densely populated industrial area. This condition is likely due to the fact that, in Surabaya NO_2 emissions are not solely influenced by industrial activities but also by dense population and transportation, given its role as a major urban center. Similarly, in Tangerang City, as highlighted in the study by Faisal and Sofyan (2019), NOx emissions were found to be predominantly generated by the industrial sector, with the transportation sector also contributing significantly.

In addition, coal-fired power plants such as PLTU in Paiton, Probolinggo are also one of the main sources of emissions as seen from NO_2 distribution analysis maps. Sarwono et al (2021), explained that the Steam Power Plant (PLTU) produces emissions such as SO_2 and NO_2 that are emitted from the PLTU chimney and spread to the atmosphere with the influence of meteorological conditions in the surrounding area. The distribution of SO_2 and NO_2 emissions in addition to being influenced by wind direction also shows higher concentrations of pollutants in the dry season than in the rainy season (Sasmita et al, 2021). Gresik itself is one of the regions that has power generation units whose activities have proven to produce a distribution of NO_2 with exposures close to emission sources have higher concentrations than those that avoid pollutant sources (Widyasari, et al., 2018).

Maula (2024), said that air pollution control policies have been well formulated, but many implementations face obstacles such as lack of coordination between institutions, less effective law enforcement and resource constraints. Many companies still use old technologies that are not environmentally friendly due to the high cost of upgrading to cleaner technologies. The lack of environmentally friendly technology and strict supervision of industrial emissions also made the situation worse.

3.2.2 Population Growth

According to the Statistics Indonesia (2024), East Java is the second-largest province in Indonesia, with 41,814,500 inhabitants. Increasing population means increasing energy requirements, transportation and other domestic activities that produce emissions. These conditions are directly correlated with the increase in NO_2 emissions. The situation is further exacerbated by weak public awareness of the environmental impact of daily activities, such as excessive use of private vehicles and the burning of garbage.

In addition, the demand for housing and other supporting facilities often leads to the conversion of green land into urban areas. According to Kristi and Boedisantoso (2015), vegetation in the form of trees, shrubs, grasses and rice fields which are usually called green open spaces (RTH) has ecological functions as urban lungs, microclimate regulators, oxygen generators, rainwater absorbers and pollutants absorbers. Thus the loss of vegetation reduces the ability of the environment to absorb and process hazardous gases such as NO_2.

Based on the results of analysis of changes in the concentration of NO_2 in East Java, it showed a decrease in NO_2 concentration in 2020 and 2021 although the decrease was not large. This condition can be possible due to the Large-Scale Social Restrictions (PSBB) during the Covid-19 pandemic. The results of NO_2 concentration satellite data in 2019 tend to be higher than 2020. A decrease in NO_2 concentration was seen early in the pandemic, the lowest in May (0.00012µg/Nm3). However, the following month tended to increase, the highest in September (0.00014µg/Nm3). The satellite imagery of NO_2 distribution is concentrated in East Java Province, namely Surabaya and Probolinggo (Wicaksono et al, 2021).

3.2.3 Transportation

Transportation is one of the main sources of nitrogen dioxide (NO_2) emissions. Based on data from the Statistics Indonesia (2021), it is recorded that the number of vehicles in East Java province is the highest in Indonesia reaching 22,774,562 vehicles consisting of minibuses, buses, trucks and motorcycles. Major cities in East Java often experience traffic jams that cause vehicles to spend more time on the road and resulting in higher emissions of NO_2. Fauzan et al (2024), mentioned that traffic congestion has a negative impact, namely air pollution due to smoke of motor vehicles, cars and other public transportations producing dust (particulate), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO) and hydrocarbons (HC). In the study by Anttila et al (2011), the increase in the primary NO_2 fraction in NOx emissions can be linked to the rising number of diesel-powered passenger cars in Finland. With the share of diesel vehicles expected to continue increasing, more NOx will be released in the form of NO_2. Therefore, in the coming years, the absolute amount of primary NO_2 emissions is also likely to begin rising.

Research conducted at the Purabaya Terminal, Sidoarjo Regency, showed that dust and NO_2 exceeded the quality standards of East Java Governor Regulation Number 10 of 2009 with an average concentration of 2.946 mg/m3 and 165.93 µg/m3 (Hikmiyah, 2018). Meanwhile, the NO_2 measurement results at the Dupak 1 toll gate in Surabaya showed that when the number of vehicles was 480 units the NO_2 value was 0.0084 ppm, when the number of vehicles 420 units the NO_2 value was 0.0080 ppm and when the number of vehicles was 1230 units the NO_2 value was 0.1183 ppm. This condition shows that the increasing number of vehicles at a point in location is proportional to the increase in NO_2 (Darmawan, 2018). In addition, Masito (2018) in his research concluded that NO_2 and SO_2 in the Kaliak Surabaya area still meet quality standards but show that NO_2 risk levels are not safe. Thus suggesting that there is an effort to control air pollution caused by motor vehicle activities by planting plants that can reduce ambient air pollutants.

Based on the results of monitoring satellite imagery, the distribution of NO_2 from the transportation sector is not very clear. This is because NO_2 emissions are generated at certain points or locations such as terminals, toll gate queues and roads with high congestion where there are many vehicles gathered. In general, it can be concluded that most of these locations are in downtown areas such as Surabaya. In contrast, the industrial sector and the location of the power plant which clearly marks the NO_2 distribution area because the emission location covers a large enough area and the resulting emissions are larger, for example the industrial sector, which is mostly in the form of areas. Hendriyono and Kusuma (2017), concluded that the total NOx emission burden from industrial activities in the SIER Industrial Area of Surabaya is 155.32 tons/year. In addition, in another study by Hendriyono and Kusuma (2017), it was stated that the NOx burden generated from the industry in Karang Pilang Surabaya was 99.56 tons/year.

4. CONCLUSION

This study identified the spatial and temporal distribution patterns of nitrogen dioxide (NO_2) concentrations in the East Java region during the 2019–2021 period. Areas with dense industrial and transportation activities, such as Gresik, Surabaya, and Probolinggo, show a higher concentration of NO_2 than other areas. Although the overall NO_2 concentration is still below the threshold set by the Meteorology, Climatology and Geophysics Agency (BMKG), urban areas remain a priority area for air quality control.

The Covid-19 pandemic has had a significant impact on NO_2 concentration, especially during the Large-Scale Social Restrictions (PSBB). Restrictions on human activity, such as transport mobility and industrial operations, contribute to a decrease in concentration of NO_2. However, after the restriction ended, the concentration of NO_2 increased again, reflecting the dependence of air quality on human activity. This highlights the need for strategic measures to reduce emissions, especially in the transport and industrial sectors.

The research findings show the importance of utilizing satellite-based monitoring technologies, such as Sentinel-5P and Google Earth Engine platforms, for accurate and efficient air quality analysis. In addition, these results provide important insight for policy makers to develop more effective air management strategies. Implementation of environmentally friendly technologies, continuous transportation development, and improvement of green open space are recommended measures to reduce NO_2 emissions and improve air quality in the future.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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