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Spatiotemporal Mapping of SO_2 and NO_2 Using Sentinel-5P Data on Google Earth Engine: A Case Study

Aditya J. Chavan[1], Asmita B. Daspute[2]

[1]SBES College of Science, Chhatrapati Sambhajinagar, Maharashtra
[2]Associate Professor SBES College of Science, Chhatrapati Sambhajinagar, Maharashtra

Abstract
This study analyzes the concentration of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) over Chhatrapati Sambhajinagar District, Maharashtra, using Sentinel-5P satellite data through the Google Earth Engine (GEE) platform. The research focuses on the spatial distribution of these pollutants during January 2025, offering insights into potential pollution hotspots and atmospheric quality in the region. The data are visualized in terms of total column density (mol/m²) and classified into relative pollution levels. The findings help inform environmental monitoring and urban air quality management.

Keywords: Google Earth Engine (GEE), sulfur dioxide (SO_2), nitrogen dioxide (NO_2).

1. Introduction

Air pollution remains one of the most pressing environmental health risks worldwide, responsible for millions of premature deaths annually (WHO, 2021). Among various pollutants, nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are critical due to their direct impact on respiratory health, their role in the formation of smog and acid rain, and their contribution to environmental degradation (Kampa & Castanas, 2008).

Urban and industrial regions like Chhatrapati Sambhajinagar District in Maharashtra are increasingly vulnerable to air quality deterioration due to rapid urbanization, vehicular emissions, and industrial activities (CPCB, 2022). Monitoring these pollutants at fine spatial and temporal resolutions is essential for designing effective mitigation policies and for ensuring sustainable development (Gurjar et al., 2016).

Traditional ground-based monitoring networks, though accurate, are often limited in spatial coverage. To address this, remote sensing technologies like the Sentinel-5P TROPOMI sensor provide an opportunity to observe air pollutants on a wide scale, with daily coverage and high spatial resolution (Veefkind et al., 2012). Integrating this data through cloud-based platforms like Google Earth Engine (Gorelick et al., 2017) enables efficient analysis and visualization of air quality trends in near real-time.

This study aims to evaluate the spatial distribution of SO_2 and NO_2 over Chhatrapati Sambhajinagar District during January 2025, using Sentinel-5P data on Google Earth Engine. The objective is to identify pollution hotspots and assess atmospheric quality using satellite-derived metrics, thereby supporting air quality management strategies in the region.

Standard Parameters for SO_2 and NO_2

Time Average	CPCB Standard (India)	WHO Standard	EPA Standard
1 hour	80 µg/m³	500 µg/m³	75 ppb (~196 µg/m³)
24 hour	80 µg/m³	20 µg/m³	–
Annual Avg	50 µg/m³	20 µg/m³	–

Table 1: Sulfur Dioxide (SO_2)

Time Average	CPCB Standard (India)	WHO Standard	EPA Standard
1 hour	80 µg/m³	200 µg/m³	100 ppb (~188 µg/m³)
24 hour	80 µg/m³	25 µg/m³	–
Annual Avg	40 µg/m³	10 µg/m³	53 ppb (~100 µg/m³)

Table 2: Nitrogen Dioxide (NO_2)

Suggested Classification Ranges (for Mapping in GEE)

Define the concentration levels in µmol/m² or Dobson Units depending on your dataset. Here's how to classify levels if you're working with molec/cm² or mol/m² (you may need to convert units accordingly).

For SO_2 (in mol/m²)

Level	mol/m² Range	Notes
Low	< 0.0001	Clean air
Moderate	0.0001 – 0.0003	Acceptable but noticeable
High	> 0.0003	Unhealthy for sensitive groups

Table 3: Classification Ranges of SO_2 (in mol/m²)

For NO_2 (in mol/m²)

Level	mol/m² Range	Notes
Low	< 0.0005	Clean air
Moderate	0.0005 – 0.0015	Acceptable/moderate exposure
High	> 0.0015	Potential health risk

Table 4: Classification Ranges of NO_2 (in mol/m²)

Thresholds Value of mol/m² and µg/m³ :

Gas	Column Value (mol/m²)	Approx. µg/m³	Air Quality Level
NO_2	0.0005	~2.3 µg/m³	Low
NO_2	0.0015	~6.9 µg/m³	Moderate
NO_2	> 0.0025	>11.5 µg/m³	High
Gas	**Column Value (mol/m²)**	**Approx. µg/m³**	**Air Quality Level**
SO_2	0.0002	~1.28 µg/m³	Low
SO_2	0.0005	~3.2 µg/m³	Moderate
SO_2	> 0.001	>6.4 µg/m³	High

Table 5: Threshold Value Ranges of SO_2 & NO_2 (in mol/m² & µg/m³)

2. Study Area

Chhatrapati Sambhajinagar District is located in the central part of Maharashtra state, India, lying between 19°18′ to 20°40′ North latitude and 74°40′ to 76°40′ East longitude. It spans an area of approximately 10,122 square kilometers and is part of the Marathwada region. The district comprises both urban and rural landscapes, including the major city of Chhatrapati Sambhajinagar, which is a prominent industrial and tourism hub.

The region experiences a semi-arid climate, with hot summers, moderate monsoons, and mild winters. Major rivers such as Godavari and Purna flow through parts of the district, contributing to its agricultural economy. Rapid urbanization, growth in industrial sectors (especially pharmaceuticals, automobiles, and textiles), and increasing vehicular density have contributed to a rise in air pollution levels, particularly in the urban and peri-urban zones.

Chhatrapati Sambhajinagar's urban core, along with industrial areas such as Chikalthana MIDC, Waluj MIDC, and Shendra, are key sources of SO_2 and NO_2 emissions, making the district a suitable location for air quality monitoring using satellite-based remote sensing tools.

3. Data and Methods

Data Sources

The primary dataset used in this study is the Sentinel-5P TROPOMI (Tropospheric Monitoring Instrument) satellite imagery, accessed via Google Earth Engine (GEE) platform.

Pollutants: Sulfur Dioxide (SO_2): Measured in mol/m² (moles per square meter).

Nitrogen Dioxide (NO_2): Measured in mol/m²

Time Period: January 1 to January 31, 2025

Spatial Resolution: Approximately 5.5 x 7 km

Temporal Resolution: Daily

Platform: Google Earth Engine (https://earthengine.google.com)

Additional datasets used for reference and boundary masking:

Chhatrapati Sambhajinagar District Boundary**:** Provided via shapefile uploaded to GEE or extracted from public datasets (e.g., Bhuvan, GADM).

Methodology

The methodology involves several steps conducted in GEE for data extraction, processing, and visualization:

Step 1: Area of Interest (AOI) Selection

The Chhatrapati Sambhajinagar District boundary shapefile is uploaded and used to mask the region from Sentinel-5P datasets.

Step 2: Data Collection

SO_2 and NO_2 bands from the Sentinel-5P dataset are filtered for January 2025.

A quality assurance (QA) mask is applied to exclude low-quality or cloudy pixels using the 'qa_value' band (if applicable).

Step 3: Unit Conversion

- The pollutant values in mol/m² are interpreted by referencing standard thresholds.
  - 1 mol/m² = 32,000 µg/m² for SO_2
  - 1 mol/m² = 46,000 µg/m² for NO_2

- These are converted to µg/m³ by estimating the vertical column height and using scaling factors from literature or standard assumptions.
  (e.g., Pope et al., 2018; van Geffen et al., 2020)

Step 4: Classification of Pollution Levels

Pollutant levels are classified into three categories based on standard guidelines (e.g., CPCB, WHO):

- **Low**
- **Moderate**
- **High**

Pollutant	Standard Limit (24-hr avg)	Threshold µg/m³ (approx)
SO_2	80 µg/m³ (CPCB)	<80 = Safe, >80 = Risky
NO_2	80 µg/m³ (CPCB)	<80 = Safe, >80 = Risky

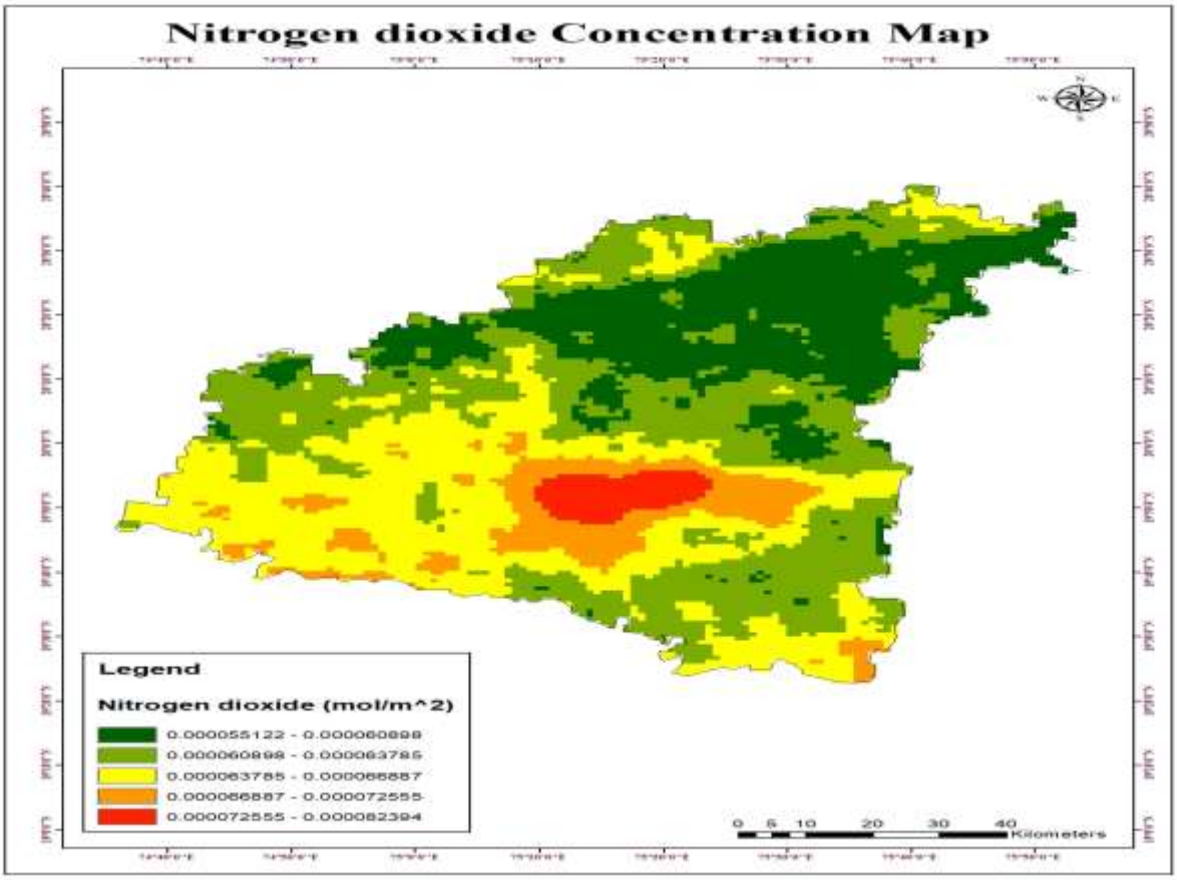
Table 6: Classification of Pollution Levels

Step 5: Visualization and Mapping

- Composite mean images for SO_2 and NO_2 are created for January 2025.
- These are visualized using color-coded gradients (e.g., green = low, red = high).
- Maps are exported for use in the Results section.

4. Result and Discussion

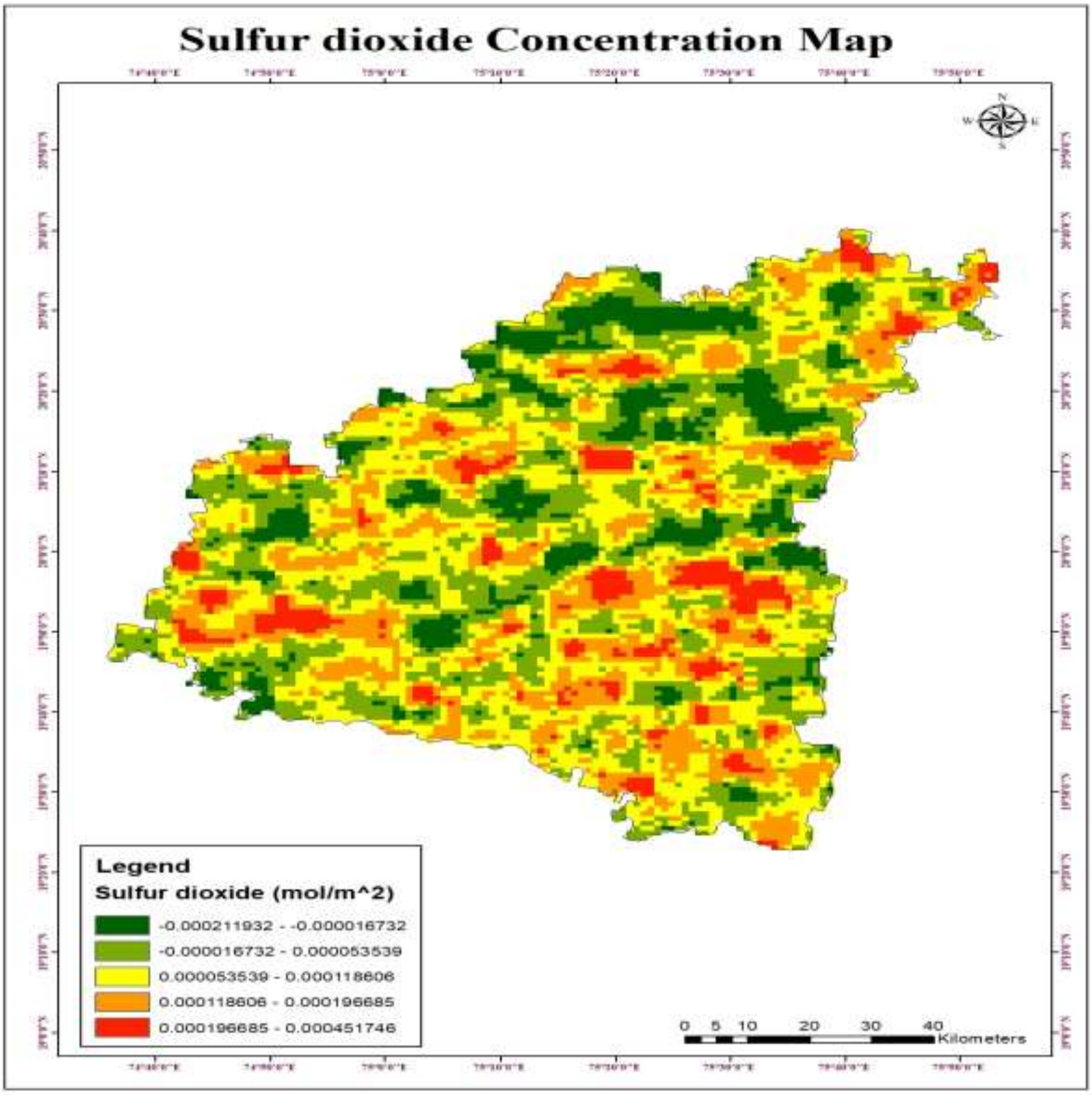
Result:



Map No. 1 : Nitrogen Dioxide (NO_2) Concentration

a). Nitrogen Dioxide (NO_2) Concentration

The as per above NO_2 Map No.: 1 shows spatial variation in atmospheric nitrogen dioxide levels, with concentration values ranging from 0.000055122 to 0.000082394 mol/m². The central and southern parts of Chhatrapati Sambhajinagar District exhibit higher concentrations, particularly shown in orange and red shades, indicating more urbanized and industrial activity. In contrast, the northern and northeastern regions display lower concentrations (green), suggesting less pollution.



Map No. 2 : Sulfur Dioxide (SO_2) Concentration

b). Sulfur Dioxide (SO_2) Concentration

Above the SO_2 Map No.: 2 for the same period shows that concentration values range from –0.000211932 to 0.000451746 mol/m². Positive concentration values dominate the region, with notably high levels (red) in southern, southeastern, and scattered central parts of the district. The green and yellow areas (lower concentrations) are primarily observed in northeastern and northwestern parts of the district.

Discussion:

NO_2 Analysis: The elevated NO_2 levels in central Chhatrapati Sambhajinagar are likely due to **vehicular emissions**, **industrial activity**, and **urbanization**, which are primary contributors of nitrogen dioxide. NO_2 is a significant air pollutant that forms from combustion processes and contributes to respiratory issues and environmental degradation (Gurjar et al., 2010).

SO_2 Analysis: SO_2 levels appear **more widely dispersed**, with spikes in **industrial and densely populated areas**. Major sources include **coal-based thermal power**, **industrial boilers**, and **vehicular exhaust**. The scattered pattern indicates **multiple minor emission sources** across the region. Negative SO_2 values (seen in the legend) may be due to **sensor noise or data correction artifacts** common in satellite remote sensing (Krotkov et al., 2016).

Comparison & Spatial Correlation: Both gases show elevated concentrations in and around urban cores, confirming that **urban and semi-urban areas are more polluted**. However, **NO_2 is more concentrated**, whereas **SO_2 is more spatially distributed**, suggesting different emission source profiles.

5. Conclusion

The spatiotemporal analysis of SO_2 and NO_2 concentrations in Chhatrapati Sambhajinagar District for January 2025 highlights that:

Central and southern areas are at higher risk of air pollution, especially for NO_2.

SO_2 pollution is more widespread, with pockets of high concentration in various directions.

These findings can help local authorities and environmental agencies target pollution control measures**,** such as promoting cleaner fuels, enhancing public transportation, and regulating emissions from industries.

Continuous monitoring using satellite-based remote sensing and platforms like Google Earth Engine offers a powerful tool for air quality management and early warning systems**.**

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