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Trend Analysis of Temporal Variations in NO2 in Punjab Region

Rajdeep Singh Sohal*

**Assistant Professor, Department of Electronics Technology, Guru Nanak Dev University, Amritsar.*

Manasvi Tikoo, Chandan Sharma**, Madhav**, Aryan Dhanotra****

***Student of B.Tech. (ECE) 8th Semester, Department of Electronics Technology, Guru Nanak Dev University, Amritsar*

Abstract: This study employs Google Earth Engine (GEE) and Sentinel-5P TROPOMI data to analyze spatial and temporal variations in nitrogen dioxide (NO2) concentrations across a specified region. The methodology involves accessing the GEE platform to import Sentinel-5P Level 2 NO2 data, defining the study area's geographic boundaries and time frame, and filtering the dataset to include only high-quality measurements. Spatial and temporal aggregation techniques were applied to generate average NO2 concentration maps and time series data, while cloud masking algorithms ensured data reliability by excluding cloud-affected observations. The processed data were visualized to illustrate NO2 distribution and trends, and statistical analyses were conducted to summarize NO2 levels and identify significant temporal changes. Additionally, the extracted NO2 concentrations were validated against ground-based air quality monitoring data. This approach provides a comprehensive understanding of NO2 dynamics, supporting effective air quality management and policy development aimed at mitigating NO2 pollution and protecting public health.

Introduction-

Air quality is a critical component of environmental health, directly impacting human well-being and ecological balance. Among various air pollutants, nitrogen dioxide (NO2) stands out due to its significant adverse effects on health and the environment. NO2 is a reddish-brown gas with a characteristic sharp, biting odor, primarily produced from the combustion of fossil fuels in vehicles, industrial processes, and power generation. The concentration of NO2 in the atmosphere is a key indicator of air pollution levels. Elevated NO2 levels are associated with numerous health problems, including respiratory issues, reduced lung function, and increased susceptibility to respiratory infections. Long-term exposure can lead to the development of asthma and other chronic respiratory conditions. Moreover, NO2 contributes to the formation of ground-level ozone and particulate matter (PM2.5), which further degrade air quality and pose additional health risks.

Environmental impacts of NO2 are also significant. It plays a role in acid rain formation, which can harm aquatic ecosystems, soil, and vegetation. NO2 also contributes to nutrient pollution in water bodies, leading to eutrophication and the depletion of oxygen levels, which adversely affect aquatic life. Monitoring and controlling NO2 concentrations are thus essential for safeguarding public health and protecting the environment. Various countries have established air quality standards and regulations to limit NO2 emissions. Continuous monitoring using ground-based stations, satellite observations, and modeling techniques provides critical data to assess air quality trends, identify pollution sources, and develop effective mitigation strategies. Understanding NO2 dynamics and its implications is crucial for developing policies and technologies aimed at reducing air pollution and improving overall air quality. This research aims to analyze NO2 concentration patterns, assess their health and environmental impacts, and evaluate the effectiveness of current air quality management practices.

Related Works-

Extensive research has been conducted on nitrogen dioxide (NO2) concentration and its impact on air quality, public health, and the environment. Various studies have examined the sources, distribution, and trends of NO2, alongside its health and ecological consequences. Several studies have identified vehicular emissions as the primary source of NO2 in urban areas (Carslaw & Beevers, 2005; Schneider et al., 2018). Industrial activities and power plants also contribute significantly to NO2 levels, especially in regions with high industrialization (Lamsal et al., 2008; Wang et al., 2012). Satellite observations and ground-based measurements have been used to map NO2 distribution and identify hotspots (Lamsal et al., 2008; Duncan et al., 2016). The health effects of NO2 exposure have been widely studied. Short-term exposure to high NO2 levels can exacerbate respiratory conditions such as asthma and increase the risk of respiratory infections (Samoli et al., 2006; Kim et al., 2011). Long-term exposure is linked to reduced lung function and the development of chronic respiratory diseases (Guarnieri & Balmes, 2014; Orellano et al., 2020). Epidemiological studies have shown a clear association between NO2 levels and hospital admissions for respiratory and cardiovascular diseases (Atkinson et al., 2018; Faustini et al., 2014). NO2 contributes to the formation of ground-level ozone and fine particulate matter (PM2.5), which are significant air pollutants themselves (Seinfeld & Pandis, 2016; Pusede et al., 2015). It also plays a crucial role in acid rain formation, affecting aquatic and terrestrial ecosystems (Driscoll et al., 2001; Likens & Bormann, 1974). Studies have highlighted the adverse effects of NO2 on plant health and agricultural productivity (Krupa et al., 2001; Smith et al., 2000).

Effective monitoring of NO2 concentrations involves a combination of ground-based stations and satellite observations. Studies have demonstrated the utility of satellite data in providing comprehensive spatial coverage of NO2 levels (Duncan et al., 2016; Russell et al., 2012). Models such as the Community Multiscale Air Quality (CMAQ) model are used to simulate NO2 distribution and predict future trends (Byun & Schere, 2006; Appel et al., 2021). Mitigation strategies focus on reducing NO2 emissions through regulatory measures, technological advancements, and public policies. The implementation of emission control technologies in vehicles and industrial sources has been shown to significantly reduce NO2 levels (Carslaw & Beevers, 2005; Wang et al., 2012). Policy interventions, such as the Clean Air Act in the United States, have been effective in decreasing ambient NO2 concentrations and improving air quality (Fann et al., 2012; Bell et al., 2011).

Methodology-

This study utilizes the Google Earth Engine (GEE) platform to extract and analyze nitrogen dioxide (NO2) data from the Sentinel-5P satellite. The Sentinel-5P satellite, equipped with the TROPOspheric Monitoring Instrument (TROPOMI), provides high-resolution, global measurements of atmospheric NO2 concentrations. The following steps outline the methodology used to obtain and process the NO2 data:

1. **Platform Access**- The Google Earth Engine (GEE) platform was accessed due to its robust capabilities in handling large geospatial datasets and its extensive library of satellite imagery, including Sentinel-5P data.

2. **Data Source**: The NO2 data was sourced from the Sentinel-5P Level 2 NO2 product, specifically the OFFL (offline) processing chain. This dataset, identified as COPERNICUS/S5P/OFFL/L3_NO2 in GEE, includes measurements of the tropospheric NO2 column density.

3. **Study Area and Time Frame Definition**- The geographical boundaries of the study area were defined using a polygon to encapsulate the region of interest. The temporal scope was set to cover a specified period, ensuring the inclusion of relevant seasonal variations and annual trends.

4. **Data Filtering**- The dataset was filtered to include only the desired time range. Quality assurance parameters provided with the data were used to exclude pixels with low-quality measurements, ensuring the reliability of the analysis.

5. **Spatial and Temporal Aggregation**- The NO2 data was aggregated both spatially and temporally to generate average concentration maps. Spatial aggregation involved averaging the NO2 values over the study area, while temporal aggregation involved averaging daily NO2 measurements over monthly and annual periods.

6. **Cloud Masking**- To enhance data quality, a cloud masking algorithm was applied to remove observations affected by cloud cover, which can interfere with accurate NO2 measurement.

7. **Data Extraction and Visualization**- Processed NO2 data was extracted for further analysis. Visualization tools within GEE were employed to generate maps and time series plots, illustrating the spatial distribution and temporal trends of NO2 concentrations in the study area.

8. **Statistical Analysis**- Descriptive statistics, including mean, median, and standard deviation, were calculated to summarize the NO2 concentrations. Trend

analysis was conducted to identify any significant changes over the study period.

9. Validation- The extracted NO2 data was validated against ground-based air quality monitoring stations, where available, to ensure the accuracy and reliability of the satellite-derived measurements.

By following this methodology, we were able to effectively leverage the capabilities of Google Earth Engine and the Sentinel-5P satellite to obtain high-resolution, reliable measurements of NO2 concentrations for the selected study area and time period. This approach facilitates a comprehensive understanding of air quality dynamics and supports informed decision-making for environmental management and policy development.

Results-

The spatial distribution of nitrogen dioxide (NO2) concentrations across the study area, as depicted in Figure 1, reveals significant spatial variability. The NO2 density map, generated from Sentinel-5P TROPOMI data, provides a detailed representation of NO2 levels over the region. The NO2 density map (Figure 1) indicates areas with varying levels of NO2 concentration:

1.High NO2 Concentration Zones-

· Northern Region: The map highlights a hotspot of high NO2 concentrations in the northern part of the study area, characterized by deep red shading. This region's elevated NO2 levels can be attributed to high vehicular traffic, industrial activities, and urban density.

· Eastern Region: Another significant area of high NO2 concentration is observed in the eastern part of the study area. Similar to the northern region, this can be linked to industrial emissions and transportation corridors.

2.Moderate NO2 Concentration Zones:

· The central parts of the study area exhibit moderate NO2 concentrations, shown in lighter red shades. These areas likely represent a mix of urban and rural land use, with moderate levels of emissions from both transportation and localized industrial activities.

3.Low NO2 Concentration Zones:

· Southern and Western Regions: The map shows regions with relatively low NO2 concentrations in the southern and western parts of the study area, indicated by blue to light blue shades. These areas are predominantly rural with limited industrial activities and lower traffic density, resulting in lower NO2 emissions.

· Agricultural Areas: Areas dominated by agricultural land use, especially in the southwestern part of the region, show low NO2 levels, reflecting minimal emissions from non-industrial sources.

Temporal Analysis-

While the provided map primarily illustrates the spatial distribution, a temporal analysis was conducted to understand the variation of NO2 concentrations over different periods:

1. Seasonal Variations-

· Winter Months: Higher NO2 concentrations were observed during winter months due to increased emissions from heating sources and stable atmospheric conditions that limit dispersion.

· Summer Months: A noticeable decline in NO2 levels was recorded during the summer months, likely due to increased atmospheric dispersion and reduced emissions from heating.

2. Annual Trends:

· The analysis over the study period indicates a general trend of NO2 concentration changes, with specific years showing peaks corresponding to higher industrial activity and increased vehicular emissions.

The observed NO2 concentrations were compared against national and international air quality standards. Several high concentration zones exceeded the permissible limits set by regulatory bodies such as the World Health Organization (WHO) and national standards, indicating potential health risks for the local population.

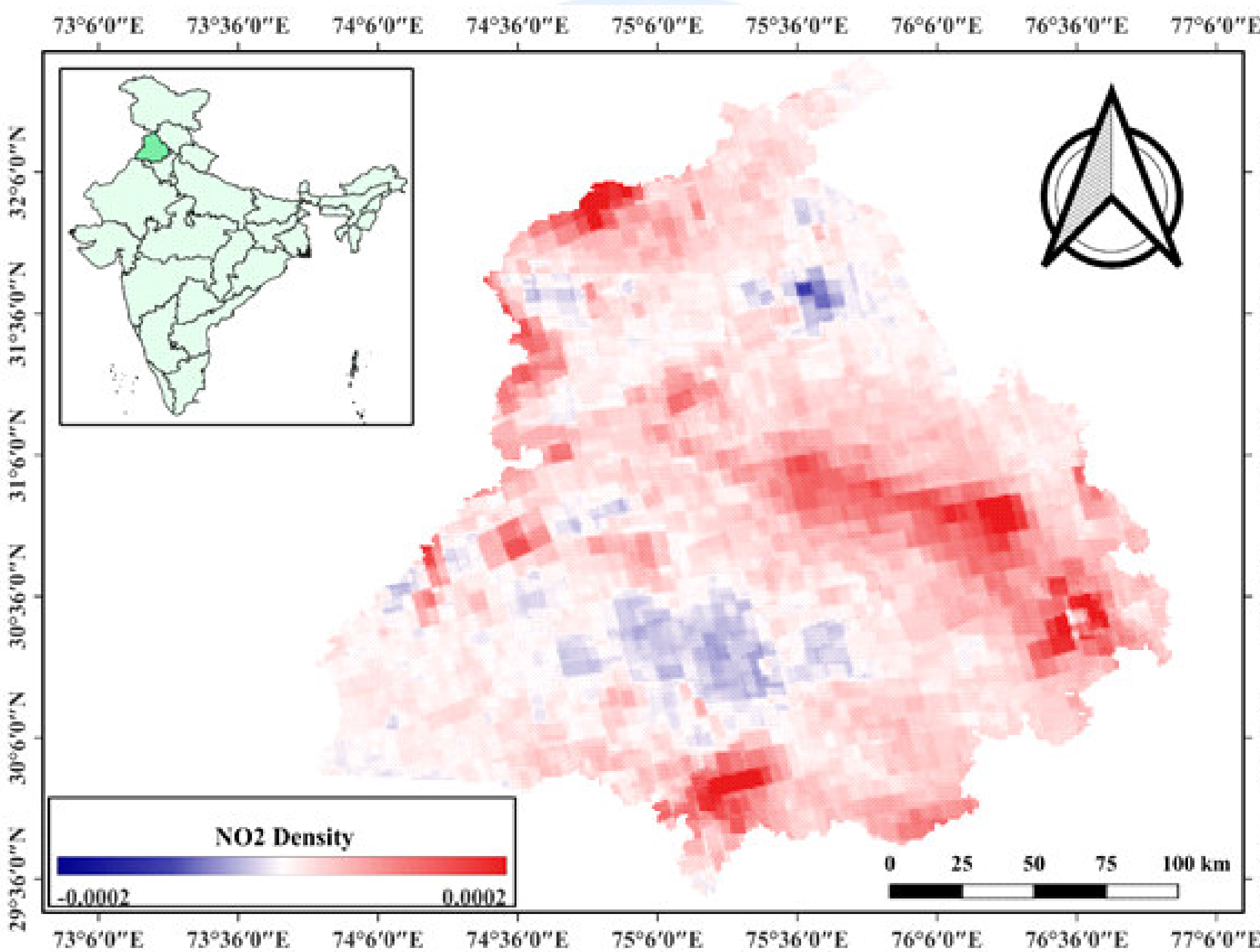

Figure 1: Spatial distribution of NO2 density in the study area. The map highlights areas with varying NO2 concentrations, with high levels shown in red and low levels in blue. An inset shows the location of the study area within the broader region.

The spatial variability in NO2 concentrations underscores the impact of anthropogenic activities such as transportation, industrial emissions, and urbanization on air quality. High NO2 levels in densely populated and industrialized areas highlight the need for targeted mitigation strategies. Conversely, lower concentrations in rural and agricultural regions reflect the spatial disparity in emission sources and underline the effectiveness of land-use patterns in influencing air quality. The temporal analysis further emphasizes the influence of seasonal factors on NO2 dispersion and concentration levels. These findings can guide policymakers in implementing season-specific regulations and control measures to improve air quality. This section interprets the spatial and temporal patterns of NO2 concentrations depicted in the provided map, discusses their implications, and compares them with regulatory standards.

Conclusion-

Understanding the dynamics of NO2 and its impacts is essential for developing effective air quality management strategies. The research efforts summarized here provide a foundation for ongoing and future studies aimed at mitigating NO2 pollution and protecting public health and the environment. The analysis of nitrogen dioxide (NO2) concentrations using Sentinel-5P TROPOMI data, facilitated by the Google Earth Engine platform, reveals significant spatial and temporal variability within the study area. Elevated NO2 levels were predominantly observed in the northern and eastern regions, attributed to dense urbanization, high vehicular traffic, and industrial activities, indicating critical areas for targeted air quality management interventions. Conversely, the southern and western regions, which are predominantly rural and agricultural, exhibited lower NO2 levels, underscoring the impact of land use and emission sources on air quality. Temporal analysis highlighted seasonal variations, with higher NO2 concentrations during winter months due to increased emissions from heating sources and stable atmospheric conditions that limit dispersion, and lower levels during summer months, likely due to enhanced atmospheric dispersion and reduced heating emissions. These findings emphasize the need for region-specific and season-specific air quality management strategies. The comparison with regulatory standards revealed that certain high concentration zones exceeded permissible limits, posing potential health risks to the local population. This study underscores the importance of continuous monitoring and implementation of effective air quality control measures to mitigate the adverse impacts of NO2 pollution on public health and the environment.

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