# A PRELIMINARY ASSESSMENT OF GEMS NO2 COMPARED WITH SENTINEL 5P TROPOMI FOR MONITORING AIR POLLUTION IN THE NATIONAL CAPITAL REGION, PHILIPPINES

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**ABSTRACT:** The use of satellite data for air quality monitoring has been continuously studied over the years to provide a global and comprehensive perspective on atmospheric conditions. Satellite-based instruments capture wide-coverage data with high temporal resolution, making them advantageous over traditional ground-based monitoring approaches, with proper validation. Launched by the Republic of Korea in 2020, the Geostationary Environment Monitoring Spectrometer (GEMS) is a latest advancement in satellite technology that provides hourly measurements of atmospheric pollutants, aerosols, and trace gases over the Asia-Pacific region during the daytime. This study aims to present an initial comparison between the nitrogen dioxide ($NO_2$) measurements obtained by GEMS and the Sentinel-5P Tropospheric Monitoring Instrument (TROPOMI) over the National Capital Region using linear regression and time-series graphs. Available GEMS and TROPOMI daily data with similar capture times were acquired for the months of July and December 2022 and processed in order to obtain the average $NO_2$ values over the study area. The daily average values for July resulted in a coefficient of determination $R^2$ of 0.6149, while the month of December resulted in an $R^2$ of 0.5105. The $R^2$ values indicate a positive relationship between the data from GEMS and TROPOMI. The time-series graphs of GEMS versus TROPOMI data presented a similar trend for most days in both months, with a few outliers or inconsistencies in the GEMS data. Comparing values from July and December, which represent the wet and dry seasons in the Philippines respectively, it was found that the average $NO_2$ values in the region were higher in the wet season for both satellite instruments. Satellite-based data can be further integrated with detailed weather data, emission inventory, chemical transport models, and measurements from ground monitoring stations once available to improve the accuracy and reliability of air quality assessments in future research developments.

## 1. INTRODUCTION

At present, air quality has been degrading especially in highly urbanized cities such as the National Capital Region in the Philippines as huge building and population density, industrialization, and high traffic volume, among others, greatly contribute to the increase of air pollutant concentrations. Proper and accurate monitoring of air quality is a necessity since high level of microscopic pollutants significantly affect human health. Through the local government units and designated agencies, regulatory measures are set for the reduction of emissions from various sources and public advisory or warnings are also made for the protection of public health. However, accurate air quality data is required to make suitable decisions. The problem of monitoring air quality roots in the inadequate amount of manual and continuous ground monitoring stations that record air pollutant concentrations at surface level, presenting insubstantial information on the spatial distribution and variation of pollutant concentrations over an area of study.

The deployment of low-cost sensors, use of satellite imagery and mathematical or dispersion models partnered with available field measurements are some of the alternatives that can be utilized to generate a representative surface of air pollutant concentrations. In this study, two satellite instruments that measure nitrogen dioxide ($NO_2$) concentrations will be compared for preliminary assessment using linear regression and trend analysis.

The Geostationary Environment Monitoring Spectrometer (GEMS) is an earth observation satellite primarily focused on monitoring the concentration of various atmospheric pollutants such as fine particulate matter ($PM_{2.5}$), $NO_2$ and sulphur dioxide ($SO_2$) for the remote evaluation of air quality and environmental conditions over the Asia-Pacific region during daytime. Initiated by the National Institute of Environmental Research (NIER) in 2008 and launched by the Republic of Korea in 2020, this instrument placed in a geostationary orbit is equipped with an advanced spectrometer that provides continuous monitoring of the atmospheric composition of an area at high temporal resolution. GEMS, together with the Advanced Meteorological Imager (AMI) and Geostationary Ocean Color Imager 2 (GOCI-2), is on board the Geostationary Korea Multi-Purpose Satellite 2 (GEO-KOMPSAT-2) mission that aims to provide an innovative approach in air quality monitoring, air transport, chemical processes, and meteorology (Kim et al., 2020). The spatial resolution of GEMS for gases is 7 km x 8 km and 3.5 km x 8 km for aerosols, acquiring data during daytime.

The Sentinel-5 Precursor (Sentinel-5P) is a single satellite mission developed by the European Space Agency (ESA) and successfully launched on October 13, 2017. This satellite carries the Tropospheric Monitoring Instrument (TROPOMI) dedicated in performing atmospheric measurements and monitoring with a spatial resolution of 3.5 km x 7 km. The TROPOMI is an imaging spectrometer of spectral wavelengths from ultraviolet to shortwave infrared in nadir view. The Sentinel-5P NRTI (Near Real Time) $SO_2$ and $NO_2$ Level 3 data is readily available from July 10, 2018 to present time in the Google Earth Engine data catalogue. Sentinel-5P data is widely used for various atmospheric observation studies. It is part of Europe's Global Monitoring Environment and Security (GMES) Space Component Programme and was used to measure key atmospheric constituents such as ozone ($O_3$) and $NO_2$ (Veefkind et al., 2012). Ialongo et al. (2019) compared the $NO_2$ concentrations derived from Sentinel-5P TROPOMI and ground-based observations in Helsinki, Finland. Consistency between the two measurements were analysed and presented a similar weekly cycle pattern, thus, the conclusion that satellite derived $NO_2$ concentrations are valuable to complement the air quality data measured on the ground, even in small cities such as Helsinki with a total land area of 191.50 $km^2$. Another study by Zhao et al. in 2020 assessed the quality of $NO_2$ by comparing it with $NO_2$ values measured on the ground by Pandora spectrometers, providing highly accurate $NO_2$ measurements through direct sun measurements. The results from this research show that both data from TROPOMI and ground-based $NO_2$ concentrations give detailed spatial patterns of $NO_2$ emissions, making it suitable for evaluation of regional air quality changes (Zhao et al., 2020).

## 2. METHODOLOGY

### 2.1 Study Area

The National Capital Region (NCR) is a highly urbanized area in the Philippines with a total area of around 619.57 $km^2$. The region is considered as the country's political and economic center and it is composed of 16 cities and 1 municipality. It is surrounded with buildings of various uses and heights, with a large volume of traffic on its primary and secondary roads. According to the Philippine Statistics Authority, NCR accounts for 12.37 % of the country's population and an average of 21,765 individuals per square kilometer in 2020. Given these circumstances, this area of interest is much more vulnerable to various environmental problems compared to its surrounding cities. A study by Bagtasa in 2019 stated that the region experiences wet season from May to October and dry season from November to April.

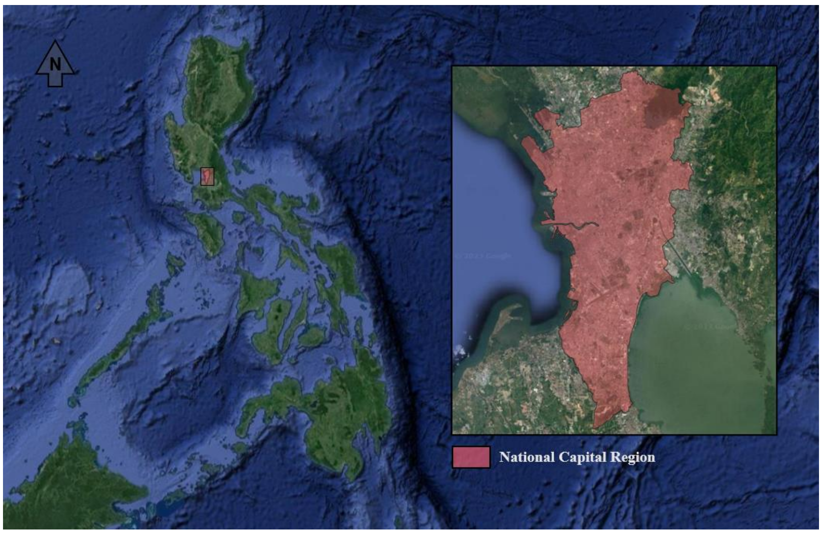


Figure 1. The National Capital Region, Philippines (Basemap: Google Satellite Map Data ©2023 Google)

### 2.2 Methodological Framework

The general process of this research includes the downloading of GEMS and Sentinel-5P NO2 data from their respective sources. GEMS data needs to undergo pre-processing for the assignment of a coordinate reference system and resampling. Preliminary assessment of the relationship of data from the two satellites is done using linear regression and the visual analysis of the daily trend. Sentinel-5P is an established satellite with its data analysed and presented in comparison with similar instruments such as the Ozone Monitoring Instrument (OMI) and in-situ measurements from ground monitoring stations in numerous published studies. Since data from monitoring stations are very limited in the study area, the $NO_2$ data from GEMS will be compared with the data from Sentinel-5P using linear regression and analysis of the daily average value trend. However, it shall be noted that these two instruments have different algorithms for processing captured images, hence, the difference in units and possible variety in results.

#### 2.2.1 Data Acquisition

The Google Earth Engine (GEE) data catalogue provides access to a wide range of earth observation data and geospatial datasets including satellite data from Landsat, MODIS, and Sentinel. For Sentinel-5P TROPOMI, a variety of pollutant concentrations (i.e. UV Aerosol Index, Cloud, CO, Formaldehyde, $NO_2$, $O_3$, $SO_2$, Methane) are available for download in the website. Using the GEE code editor, a script was developed using the Javascript language to acquire the needed $NO_2$ data. The Environmental Satellite Center (ESC) of the Korean National Institute of Environmental Research (NIER) operates the GEMS satellite and provides raw data for public consumption with the goal of contributing to climate change and human health research. The website (https://nesc.nier.go.kr/ko/html/index.do) allows the download of GEMS data with a daily limit of 20 GB.

Daily images from July and December 2022 were downloaded to represent the wet and dry season, respectively. The metadata of Sentinel-5P data containing the image's acquisition information such as the date and time, orbit path, spectral information, etc. is checked using a function in the GEE code editor. The listed capture time is noted and the GEMS image with the closest capture time is downloaded from the NIER ESC website.

#### 2.2.2 Pre-Processing of GEMS Data

Acquired GEMS $NO_2$ data are in network common data (NetCDF) format that is usually used for storing multidimensional scientific data such as weather parameters. For these data to be compatible with GIS applications and tools, it needs to be converted to a widely supported image format such as tag image file (TIF). Conversion to TIFF also allows the user to extract and work with the data variables separately. The conversion from NetCDF to TIFF was implemented using a Python script that includes several processes. First, a coordinate reference system is set to provide a spatial context of the image. Voronoi polygons were created as a method for partitioning an area into cells. These polygons are commonly used in spatial analysis and territorial division. Lastly, the images are resampled from the original resolution of 3.5 km x 8 km into 3.5 x 3.5 km to match the produced resolution of Sentinel-5P for improvement of data quality in further analysis.

#### 2.2.3 Comparison of GEMS and Sentinel 5P TROPOMI NO2 Data

The Sentinel-5P and GEMS $NO_2$ data in raster format should have similar cell sizes due to the resampling method from pre-processing procedures. These are then converted into points wherein the values of each point is extracted and recorded in a CSV file. The average value for the totality of the study area were calculated for all days of the month and the comparison of values using linear regression and trends analysis were all implemented using MS Excel.

## 3. RESULTS AND DISCUSSION

Figure 3 and 4 presents the results of linear regression and trends of the daily average $NO_2$ values for the whole region in the month of July. The coefficient of determination ($R^2$) is 0.6149, indicating a positive relationship between the two datasets. For the $R^2$, a value closer to 1 means that there is a perfect relationship between two variables while a value of 0 suggests that there is no correlation. The trend of $NO_2$ values also shows an agreement between GEMS and Sentinel-5P values for most days of the month, with the GEMS data obtaining a generally higher value. It can be observed that for both figures, the units of each instrument observation were not modified and presented only in secondary axes for comparative purposes. Figures 6 and 7 shows the corresponding results for December 2022. From the given observation points, the resulting $R^2$ is 0.5105, which also indicates a positive relationship between the two variables. The trend presents a similar pattern for most days, although an outlier can be shown in the date of December 21 and an opposing trend can be observed between December 25 to 29.

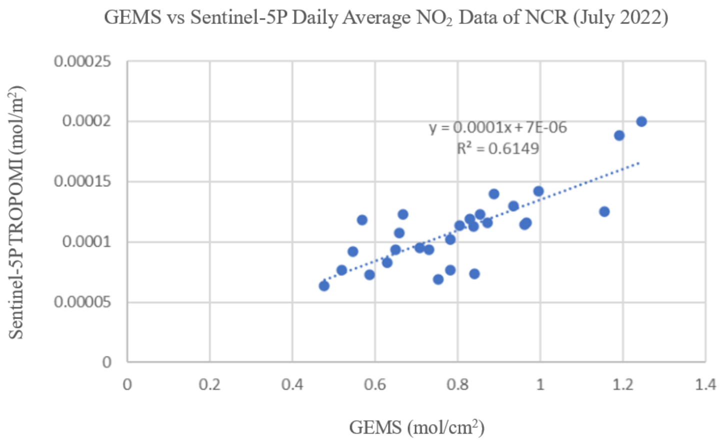


Figure 3. Linear Regression of the daily average NO2 data of GEMS vs Sentinel-5P TROPOMI for July 2022

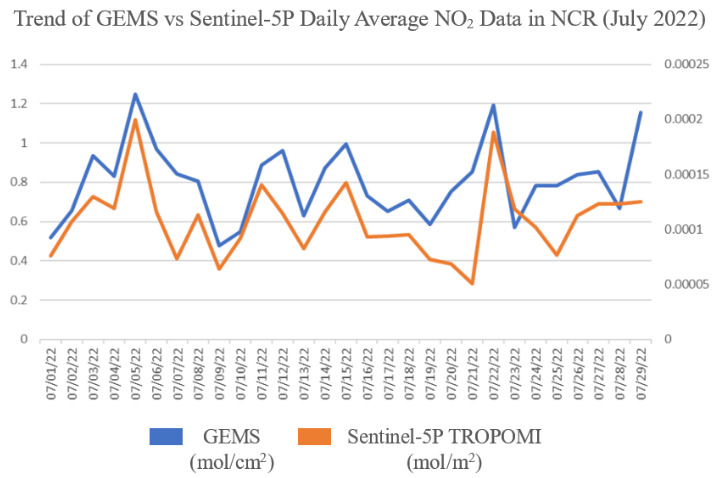


Figure 4. Trend of GEMS vs Sentinel-5P TROPOMI daily average $NO_2$ data for July 2022

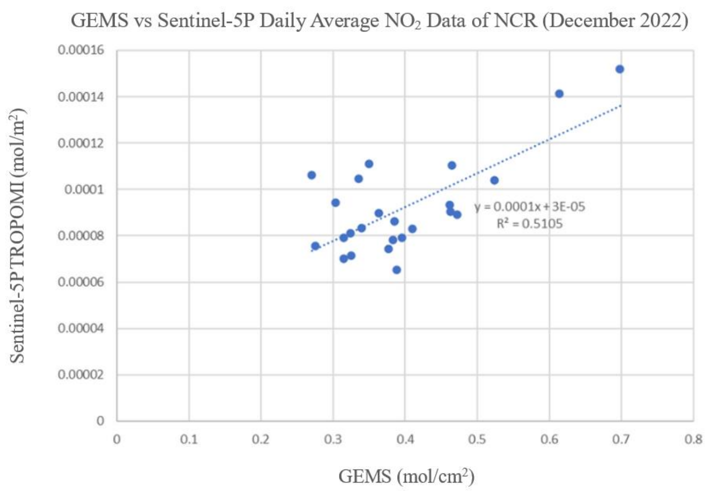


Figure 5. Linear Regression of the daily average NO2 data of GEMS vs Sentinel-5P TROPOMI for December 2022

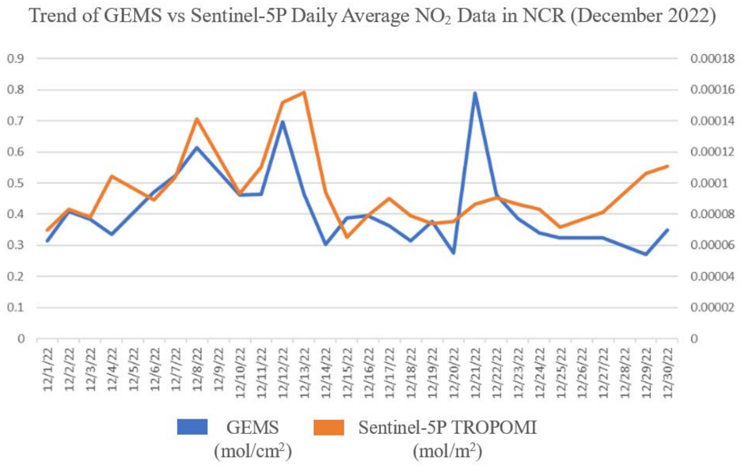


Figure 6. Trend of GEMS vs Sentinel-5P TROPOMI daily average NO2 data for December 2022

The scope of this study is limited to a month of wet and dry season due to constraints in time and resources. Future studies may consider using longer periods of data that can better describe the changes of $NO_2$ concentration in the region at different seasons or specific events that may trigger outliers in data. Whether the $NO_2$ values are generally higher during the wet or dry season can be studied with more data and weather parameters, if applicable, and since GEMS provides hourly observation during the daytime, the diurnal variation of $NO_2$ concentration is also possible with ground validation.

## 4. CONCLUSIONS

Sentinel-5P data has been included in several published articles as a complement to ground data for measuring air pollutant concentrations. GEMS, the world's first geostationary environmental satellite, should also serve the same function with proper research. It was observed that the $NO_2$ values from Sentinel-5P and GEMS are positively correlated ($R^2$ = 0.6149 for July 2022; $R^2$ = 0.5105 for December 2022) from the results of linear regression and trend lines. It is possible to utilize data from satellite imagery as an alternative for monitoring the air quality in urban regions especially those with no means of accurately gathering data from the surface. This study only presents a preliminary assessment of the comparison between the data captured by Sentinel-5P TROPOMI and GEMS. In-depth research that incorporates satellite data with other essential factors such as weather information, traffic data, and models may be done once adequate air pollutant concentration data from ground monitoring stations are available for accuracy and validation purposes.

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