ESTIMATION OF NITROGEN DIOXIDE (NO2) CONCENTRATION USING FENGYUN-4A DUST STORM DETECTION (FY-4A DSD) PRODUCT DURING THE COVID-19 LOCKDOWN IN METRO MANILA, PHILIPPINES

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ABSTRACT:

The coronavirus disease was discovered in 2019 (COVID-19) and was eventually declared by the World Health Organization (WHO) as a global pandemic on March 11, 2020. This study aims to determine the correlation of Dust Storm Detection (DSD) index from the Fengyun-4A (FY-4A) data, NO2 ground observations, and daily positivity rate of COVID-19 cases in Metro Manila and predict the confirmed daily cases of COVID-19 using the established correlations. FY-4A DSD products were used to obtain different Dust Storm Indices (DSI) and daily COVID-19 confirmed cases were tallied during the period November 01-30, 2020, and March 01-31, 2021. Ground-observed NO2 levels from Environmental Management Bureau (EMB) monitoring stations were gathered for validation and regression analysis. Results of linear regression analysis between the DSI and NO2 exhibited a weak correlation (0.24) with the available observations at the specified period. Ground-observed NO2 levels exhibit the same trend with the daily positivity rate of COVID-19 considering only a smaller area and short period of observations. Moreover, results showed a weak correlation (0.07) between the positivity rate of COVID-19 case as a function of the DSD Index and ground-observed NO2 levels. Uncertainty of results from this study may be attributed to the fact that it has focused on a relatively small area due to limited available ground observations. Therefore, it is recommended to apply the same analysis on different periods of observations using as many NO2 level ground observations as available and determine if variables follow the same trend and correlations as reported in this study.

1. INTRODUCTION

1.1 Background

The communicable nature of COVID-19 has become a great concern and crippled the health status of many countries in the world. COVID-19 is a respiratory disease caused by the coronavirus that makes infected people experience fever, cough, and shortness or difficulty in breathing, among others. (Sauer, 2021). Meanwhile, prolonged exposure to gaseous pollutants such as nitrogen dioxide (NO2), sulphur dioxide (SO2), particulate matter (PM), and carbon monoxide (CO) can result in respiratory illnesses and mortality (Comunian et. al, 2020; David et. al 2019; Faustini et al, 2014; He et. al).

The Philippine government, as part of its strategy to contain the spread of the disease, imposed a nationwide lockdown on March 15, 2020, that lasted for 6 months, but succeeding reimpositions of lockdowns were implemented thereafter. Lockdowns were imposed as an effort to slow down and contain the virus from spreading to the local community. Experts believed that the long nationwide lockdown had shown positive results in terms of the significant decrease in the growth rate of the number of people infected with the disease, especially in Metro Manila (Dancel, 2020). Moreover, lockdowns were also seen as a cause in the improvement of air quality not only in the Philippines but also all over the world. (Mongabay, 2020).

Remote Sensing (RS) satellite data are used to better understand air pollution levels in the tropospheric column of the Earth's atmosphere (Liji Mary David and Nair, 2013; Fishman et al., 2008; Martin 2008; Sellitto et al., 2011). But the adverse effect of air pollution in human health can be observed at the canopy-level near the surface of the Earth in developing countries (Sidiqui et al., 2020). According to IQAir website, as of 2020, the Philippines rank 70th place among the most air polluted countries in the world with one of the main causes of air pollution coming from motor vehicles while the rest comes from factories and burning of organic matter.

This paper aims to determine the correlation of DSD Index from the Fengyun-4A data, NO2 ground observations and with the daily positivity rate of COVID-19 cases in Metro Manila and to predict the daily confirmed cases of COVID-19 using the established correlations.

2. REVIEW OF RELATED LITERATURE

2.1 Air Quality Data from Satellite Images

Nowadays, remote sensing from different earth orbiting satellites have been used to monitor the air pollution levels in the Earth's atmosphere. Recently, many research papers focused on the effects of air pollutants such as NO2, and SO2 that contribute to the increase of air pollution level in the atmosphere (Zhou, et al., 2021; Virghileanu, et al., 2020; Siddiqui et al., 2020, Lim, 2009; Gupta et al., 2006). These pollutants play an important role in understanding the air pollution level and estimating the approximate location of emission sources of these pollutants in an area. (Virghileanu, et al., 2020; Siddiqui et al., 2020, Lim, 2009; Gupta et al., 2006). Understanding the effects of these pollutants gives scientists and decision makers insights on how to apply proper mitigation strategies and implement policies for the reduction of greenhouse gas emissions.

A recent study of Virghileanu, et al. (2020) reported the successful use of Sentinel 5P data in monitoring nitrogen dioxide concentration in Europe. It was emphasized that due to the high spatial resolution of these data, air quality monitoring is possible

at different scales of analysis, from cities up to a global coverage. Moreover, another highlight of this satellite data is the reliability of its daily global coverage providing stakeholders with continuous surface data. As a result, monitoring of the spatial distribution of different pollutants for a specific time is made possible.

Siddiqui et al (2020) also looked at the effectiveness of Sentinel 5P in monitoring the NO_2 level during the 3 phases of lock down in India. They highlighted that the long term NO_2 spatial analysis using TROPOMI products from Sentinel 5P could point out the hot spots of higher concentration of NO_2 pollutants due to several anthropogenic (e.g., domestic, vehicular, and industrial emissions) and natural causes. Moreover, they also pointed out that the lockdown period in India, especially in its bigger cities, reveals a great reduction of NO_2 emission. Another noticeable discovery in their study was corona positive cases and the fatality cases in their 8 major cities are all located in areas with high long-term NO_2 exposure.

## 2.2 Fengyun-4A (AGRI) DSD Product Data Acquisition

Fengyun-4A (FY-4A) is a next generation geostationary meteorological satellite of China that was launched on December 11, 2016. Aboard the satellite is the Advanced Geosynchronous Radiation Imager (AGRI) which takes full-disk images at a 15 min interval and has 14 spectral bands at 0.5-4km resolution. Moreover, FY-4A offers a full disc image of aerosol optical depth (AOD) which covers a large area.

In a study conducted by Xia et al (2020), the effectiveness of data assimilation of AOD from Fengyun-4A was tested. An aerosol data assimilation experiment was constructed as derived from the AOD of Fengyun-4A AGRI data and an aerosol data assimilation system based on Gridpoint Statistical Interpolation (GSI). This assimilation experiment was applied and tested in a heavy dust storm event that happened over East Asia during 12-14 May 2019 to evaluate its effectiveness in forecasting. Based on the results of their experiment, assimilation of AOD data has improved the initial field of the model. The assimilation of AOD provides much more aerosol observation information and a more accurate description of the model. It also showed a positive effect on prediction, improved the intensity and distribution of each variable, and made it more consistent with accurate observation. Also, statistical results showed that the assimilation system coincides better with the ground-observe data. Furthermore, FY-4A AOD DA and aerosol forecasts greatly improved compared to independent AOD observations from AERONET sites. The work of Xia et al (2020) has also shown that the FY-4A AOD data assimilation system has a broad development prospect in the application in air quality prediction.

With the above examples, it is clear that the use of remote sensing data is effective in monitoring air quality. To date, there is no available literature regarding the use of Fengyun-4A data to monitor air quality in this paper's study area. This study therefore aims to examine the effects of the lockdowns in 2020 and 2021 on the air quality in Metro Manila using Fengyun-4A satellite data and assess the effectiveness of Fengyun-4A in air quality monitoring.

3. METHODOLOGY

Fig. 1 shows the general methodology of this study. The hourly data of FY-4A DSD products were obtained on the periods of November 01 to 30, 2020 and March 01 to 31, 2021. DSD products were post-processed for image registration and clipping on the target area. DSD level index in the validation point was extracted and compared with the ground-based observations.
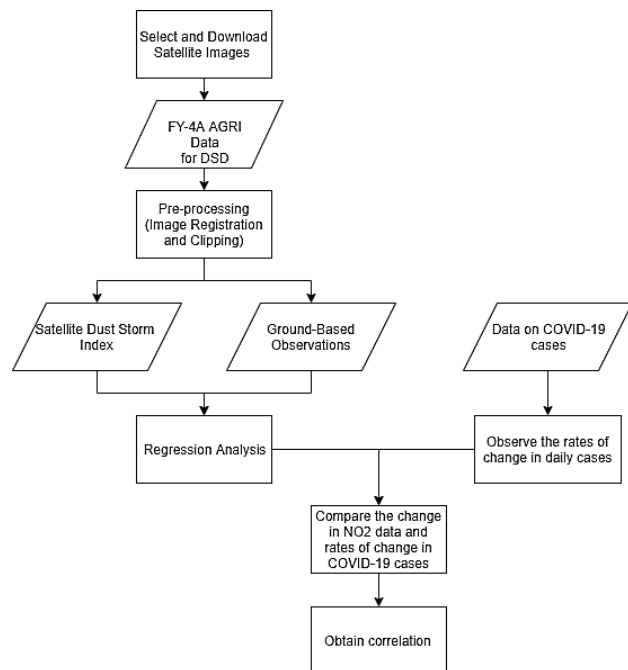
Figure 1. Flowchart of the general methodology of this study.

A linear regression analysis was made relating the two sets of measured observations. A similar process was also done with the daily rates of confirmed COVID-19 cases to determine the relationship between the COVID-19 cases with the other two observations. Lastly, the correlation between the three factors was then determined.

3.1 Study Area
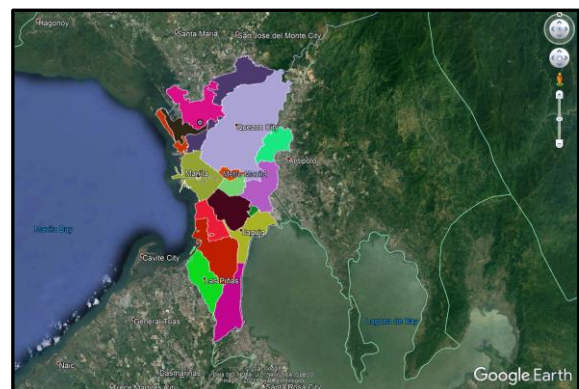
Figure 2. Metro Manila as the study area with its cities and municipality represented in colored polygons as overlaid in Google Earth.

The study area was the Metro Manila (Fig. 2) which is also known as the National Capital Region (NCR). Metro Manila is bounded by 14° 20' 57.408"N to 14° 46' 52.72" N along latitude

and 120° 55' 1.01" E to 121° 07' 55.46" E along longitude. On 21 March 2021, Metro Manila and nearby provinces of Cavite, Laguna, Bulacan and Rizal were placed under an Enhanced Community Quarantine (ECQ) by a memorandum from the Office of the Executive Secretary of the Office of the President due to a significant surge of confirmed COVID-19 cases. The concerned areas were termed as the "NCR Bubble Plus".

Based on the 2015 national census, the NCR Plus has a total population of 25,766,933 and is projected to have an overall population of 28,214,869 by 2020 with 13,802,714 or 48.92% residing in the NCR.

3.2   Fengyun-4A Dust Storm Detection Product

An hourly data of Full-disc FY-4A DSD product (Fig. 3) was acquired from periods of November 01 to 30, 2020 and March 01 to 31, 2021. FY-4A DSD products were acquired through the Fengyun Satellite Data Center of the National Satellite Meteorological Center. Some of the downloaded data do not have a complete set of hourly DSD data. The daily DSI values extracted from these images were averaged from the hourly data acquired.

Fengyun DSD products use Severity Index (SI) from Level 0 to Level 12. Due to lack of available documentation of the said product, it was assumed that SI Level 0 and 12 were the lowest and highest DSD index values observed, respectively, at the time of observation.
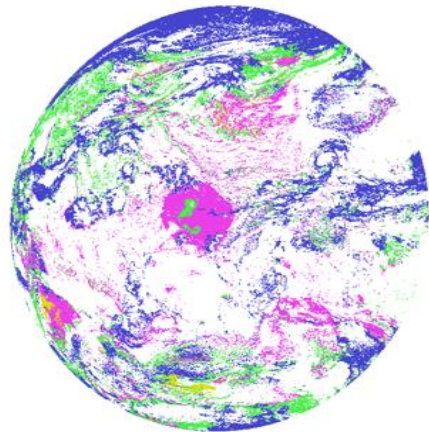
Figure 3. Full-disc FY-4A DSD product acquired from March 01, 2021 observations.

3.3   Ground based observations Data

There are several ground-based stations established at various locations in the entire country by the Environmental Management Bureau. These ground-based stations gather NO_2 levels and other air compositions with relatively high accuracy. However, these stations are limited in number, and their distribution is sparse and asymmetrical leading to the spatial-temporal variation in NO_2 levels.

In Metro Manila, there are 13 ground base stations but only two can obtain NO_2 levels. The NAMRIA and ATENEO stations measure daily average NO_2 levels. However, the ATENEO ground base station encountered an analyzer error in September 2020. With this, the NAMRIA base station in Taguig City has become the only ground base station with NO_2 measurements available and used for this study.

3.4   Daily Confirmed Cases of COVID-19

The number of confirmed daily COVID-19 cases in Metro Manila was obtained using the data drop of the Department of Health (DOH). Confirmed daily COVID-19 cases in November 2020 and March 2021 were selected as these were the lowest reported cases and the highest transition peak recorded, respectively (Fig. 4). The tally for the daily confirmed COVID-19 cases is made publicly available online on the official website of the DOH COVID-19 tracker (https://doh.gov.ph/covid19tracker).


Figure 4. Reported confirmed daily COVID-19 cases in NCR. Dates in red polygons are the selected period of observation (i.e., Nov. 2020 and Mar. 2021).

4.   RESULTS AND DISCUSSION

4.1   Confirmed COVID-19 Daily Cases

4.1.1. Daily Cases on Metro Manila: The reported daily cases for Metro Manila are shown in Figs. 5 and 6. The data collected was based on the reports by different accredited laboratories, hospitals, and local government units consolidated and reported on the DOH data drop on its online COVID-19 tracker.
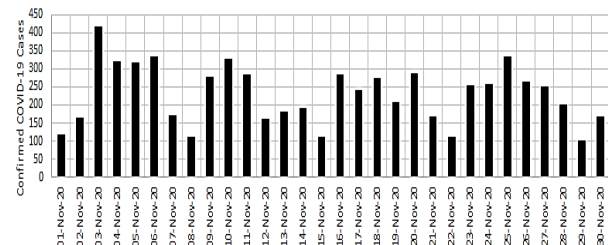
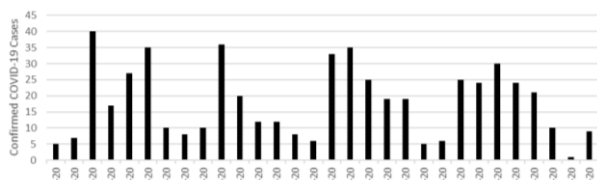**Figure 5.** Daily cases in NCR from 11/01 to 11/30, 2020.
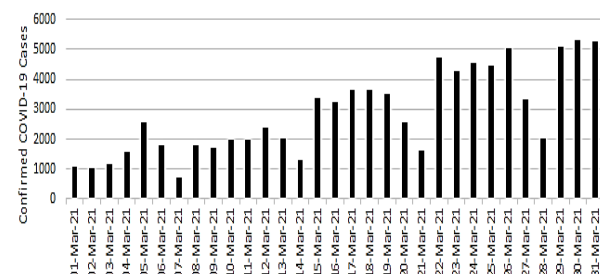
**Figure 6.** Daily cases in NCR from 03/01 to 03/31, 2020.

The Nov 2020 period recorded the relatively lower COVID-19 cases with 101 and 418 as the lowest and highest cases for the said month, respectively. In addition, similar weekly trends can also be observed for this month (Fig. 5) where weekdays exhibit higher cases than on weekends. However, for the Mar 2021

period, there was an increasing trend on the daily cases. The lowest and highest COVID-19 daily case reported for Mar 2021 was 721 and 5,298, respectively.

4.1.2. Daily Cases on Taguig City: Reported daily cases in Taguig City are shown in Figs. 7 to 8. Fluctuating trends of COVID-19 cases can be observed during Nov 2020 in Taguig City (Fig. 7) but these were relatively low compared to the reported cases for the same city in Mar 2021 and with an increasing trend of daily COVID-19 cases similar with the trend for the whole Metro Manila reported daily case.

**Figure 7.** Daily cases in Taguig City from 11/ 01 to 11/30, 2020.
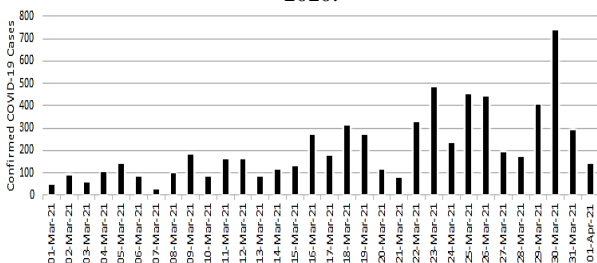
Figure 8. Daily Cases on Taguig City from March 01-31, 2021.

4.2 Dust Storm Index from FY-4A

The DSD index in Taguig City during the Nov 2020 and Mar 2021 periods are shown in Figs. 9 and 10, respectively. The daily DSD index was calculated by averaging the hourly data of FY-4A.
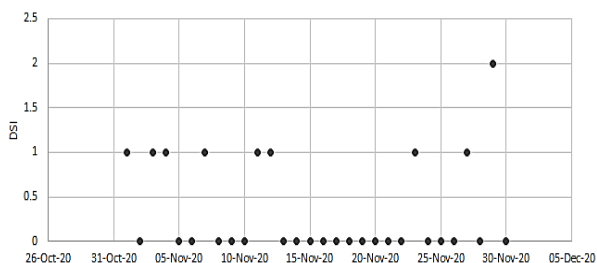

Figure 9. Dust Storm Index from 11/01 to 11/30, 2020 in Taguig City.
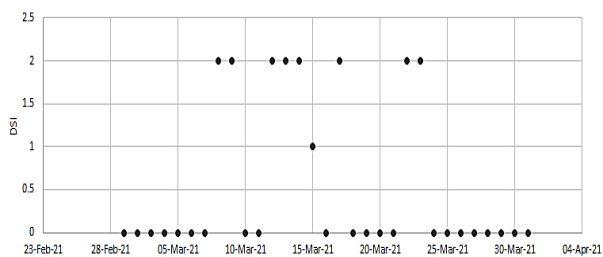
Figure 10. Dust Storm Index from 03/01 to 03/31, 2021 in Taguig City.

4.2.3. Fengyun-4A DSD Product: The FY-4A DSD products used in this study are shown in Figs. 11-12. The NAMRIA and ATENEO base stations were overlaid and the corresponding DSD index (DSI) values were extracted. DSI at NAMRIA station in Taguig City has values from Level 0 to Level 2 on the two separate months of observations. Meanwhile, the ATENEO stations recorded mostly DSI values ranging from Level 0 to Level 3, except for a single day where a Level 12 index was observed.

DSI values can be used to correlate with other possible events that happened in the area (e.g., community lockdowns, reopening of industries) that may contribute to the decrease/increase of the DSI and estimate NO_2 and SO_2 levels. Obtaining higher correlation between DSI and NO_2 (or any air pollutant) provides additional support in remote monitoring of air quality.
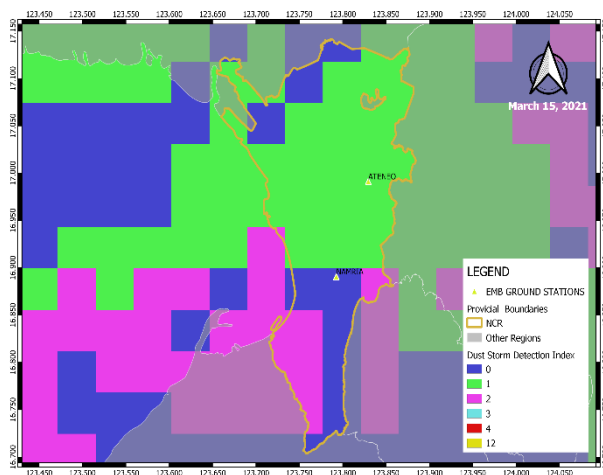
Figure 11. FY-4A DSD product acquired on March 15, 2021.

4.3 Ground Based NO_2 Observations

4.3.1. NO_2 observations at NAMRIA Station: The NO_2 observations at the NAMRIA station located in Taguig City are shown in Figs. 13 and 14. It can be inferred that the increasing and decreasing trend of NO_2 values indicates a relatively similar trend with the reported daily case in Taguig City. These trends are associated with sources of NO_2 including transportation. Increase in transportation mobility in an area contributes to the daily increase or decrease of confirmed COVID-19 daily cases. In a study conducted by Armano Carteni et al. in Italy, on the role of transport accessibility with the spread of the COVID-19, the estimation results show about 40% correlation between the COVID-19 infections and transport accessibility. The greater the accessibility of an area, the easier the virus reaches its population (Carteni, et. al., 2021).

The regression plot of ground-based NO_2 observations along x-axis and the corresponding DSI value along y-axis obtained from the FY-4A is shown in Fig. 15. There is a weak correlation between the NO_2 levels and DSI. Using observed values at the NAMRIA station, results show that the assumption of a lower DSI value corresponding to lower ground observed NO_2 level does not hold true. Therefore, one should exercise caution when drawing conclusions on the trend in NO_2 levels based on DSI values FY-4A alone.
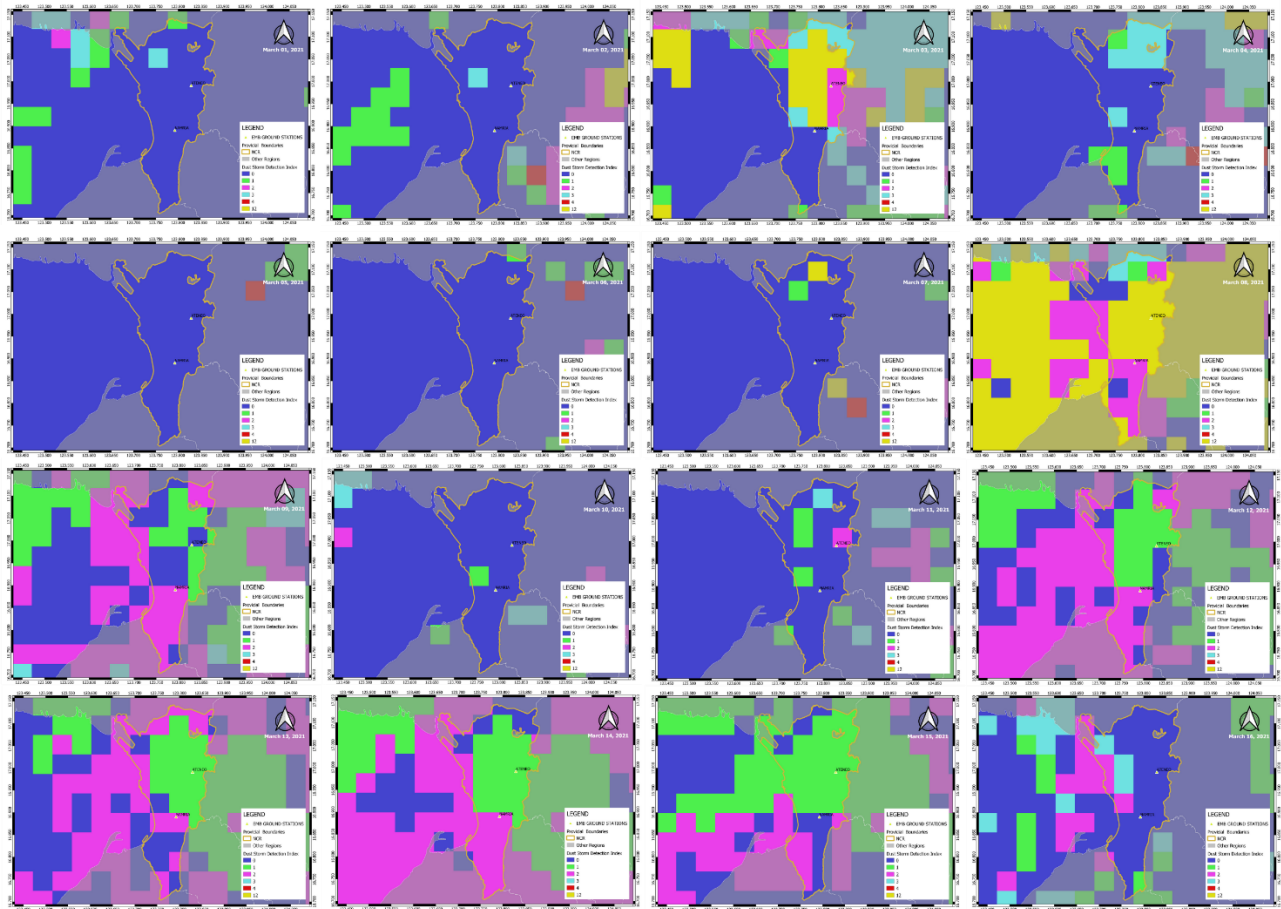
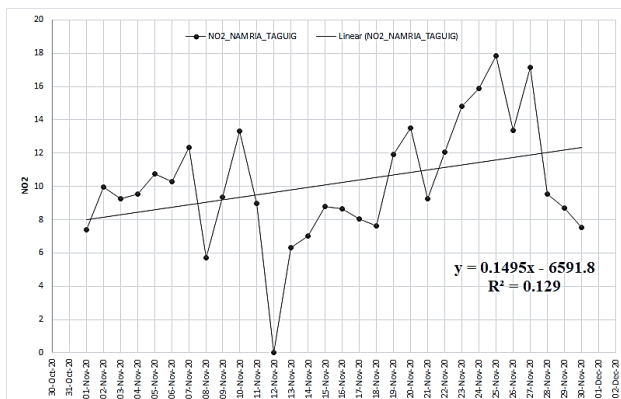**Figure 12.** Mean FY-4A daily DSD from 03/01 to 03/16, 2021.

Figure 13. Ground-based observations of NO₂ levels at NAMRIA station on 11/01 to 11/30, 2020.
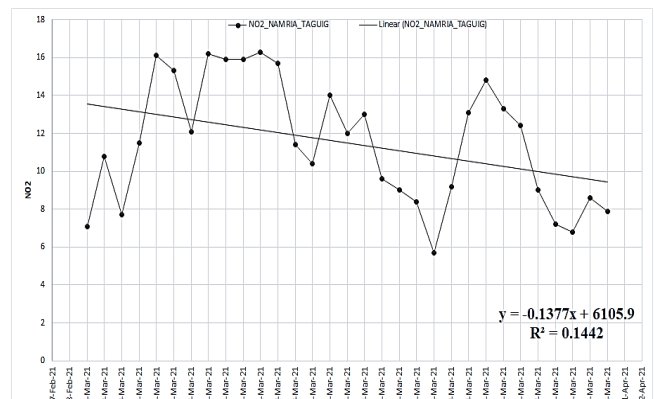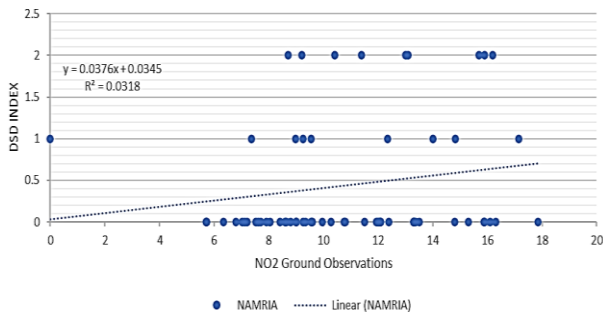

Figure 14. Ground-based observations of NO₂ levels at NAMRIA station on 03/01 to 03/31, 2021.

Figure 15. Ground-based observations of NO_2 plotted against the DSD Index at the NAMRIA station in Taguig City.

4.4 Correlation Analysis

A correlation matrix (Table 1) was computed for the three parameters (i.e., DSI, NO_2, Cases). "DSI" corresponds to the FY-4A DSD index, "NO2" for the ground-observed level of the pollutant, and "Cases" for the confirmed daily COVID-19 cases. Results show that the DSI and NO_2 ground observations exhibited higher correlation with about 0.24. Meanwhile, the correlation between confirmed COVID-19 cases to DSI and ground observations are about 0.07 and 0.05, respectively indicating weak correlation between these sets of parameters.

	DSI	NO2	CASES
DSI	1.00	0.24	0.07
NO2	0.24	1.00	0.05
CASES	0.07	0.05	1.00

Table 1. Correlation matrix for the three parameters considered in this study.

A multiple regression analysis also shows a weak correlation value of about 0.07 for the three parameters observed. Fig. 16 shows the predicted number of COVID-19 cases as plotted against the observed value as a function of DSI and NO_2 ground observation (Eq. 1).
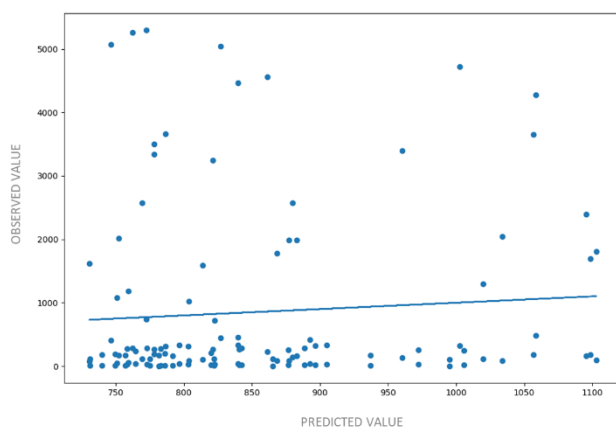
Figure 16. Predicted against observed number of COVID-19 cases as a function of DSI and NO2 levels.

The predicted value was calculated using Eq. (1) which was derived from the multiple regression analysis.

$$Cases = 110.769 * DSI + 14.341 * NO2 + 648.997 \quad (1)$$

where:
- Cases = predicted number of COVID-19 cases
- DSI = FY-4A Dust Storm Detection Index
- NO2 = ground-observed NO_2 levels

5. CONCLUSIONS AND RECOMMENDATIONS

Values of the Dust Storm Index (DSI) from FY-4A is too generalized when validated with the ground-based NO_2 observations. An abrupt change in DSI value has a corresponding significant effect on the daily average value of DSI values. Most of the DSI values in NCR range from Level 0 to Level 3 for a 2-month observation period. Meanwhile, ground-observed NO_2 levels exhibit the same trend with the number of daily positive cases of COVID-19 only in consideration of a smaller area and short period of observations. The DSI and NO_2 values exhibited a weak correlation (0.24). Similarly, the positivity rate of COVID-19 cases as a function of DSI and ground-observed NO_2 levels showed a weak correlation (0.07).

Observations made in this study were concentrated on a smaller area due to inadequate amount of existing ground observations. Therefore, it is recommended to apply the same analysis on different periods of observations using more ground observations of NO_2 levels and examine if they follow the same trend and correlations.

Nonetheless, this study has demonstrated how remotely sensed data can be used to assess the impact of lockdowns due to COVID-19 on air quality. With more validation stations on the ground and additional RS-derived air quality data, it is expected that the proposed methodology could be improved further.

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