ACRS 2022
MONGOLIA

TIME-SERIES ANALYSIS OF AIR QUALITY IN MAJOR CITIES IN THE PHILIPPINES DURING THE COVID-19 PANDEMIC THROUGH SENTINEL-5

Cara Patricia Canlas[1], Arlo Jayson Sabuito[1], Archie Veloria[1], Gay Jane Perez[1,2]
[1]Philippine Space Agency, University Laboratory for Small Satellites and Space Engineering Systems (ULyS3ES) Building, University of the Philippines, Diliman, Quezon City, Metro Manila, Philippines
Email: cara.canlas@philsa.gov.ph, arlo.sabuito@philsa.gov.ph, archie.veloria@philsa.gov.ph, gay.perez@philsa.gov.ph
[2]Institute of Environmental Science and Meteorology, University of the Philippines, Diliman, Quezon City, Metro Manila, Philippines
Email: gpperez1@up.edu.ph

KEY WORDS: Sentinel-5, Air Quality, Rainfall, Land Surface Temperature, Pandemic Lockdown

ABSTRACT: Air pollution causes respiratory ailments and drives climate change. Air quality is driven by emissions from various sources, weather patterns, and transport of pollutants. Satellite analysis of pollutants in the atmosphere can provide temporally consistent and spatially wide measurements. In this study, the monthly concentrations of Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Carbon Monoxide (CO), and Ozone (O_3) from the Sentinel-5 Tropospheric Monitoring Instrument (TROPOMI) were analyzed in four major cities in the Philippines, representing different climate types. Satellite-based measurements of land surface temperature and rainfall were used to investigate meteorological effects to air pollutants. Seasonal patterns were observed in the time series of NO_2, O_3 and CO alongside rainfall and LST. During the dry season, high LST and low precipitation is observed to be associated with increase in NO_2, O_3, and CO concentrations. On the other hand, wet seasons show decreases in concentrations of air pollutants, consistent with the washout effect. The NO_2 average concentration in NCR is 1.9, 2.1, 2.3 times higher than in Metro Cebu, Davao City, and Legazpi City, respectively. In contrast, SO_2 average concentration is highest in Legazpi City due to the nearby active volcano by a maximum factor of 1.8 compared to other cities. In addition, air quality changes brought about by community quarantines were examined since the onset of the COVID-19 crisis. Transition from the pre-quarantine period to the first lockdown shows sudden decrease by 28% in satellite-based retrievals of NO_2 in NCR, mainly due to reduced anthropogenic emissions. As tiers of community quarantines were introduced, an increase in pollutant concentrations was observed, returning to pre-pandemic air quality as the guidelines ease physical and economic restrictions. Monitoring and analyzing the patterns in concentration of air pollutants in relation to meteorological and anthropogenic drivers can help in the air quality management in the country.

1. INTRODUCTION

The Coronavirus Disease-2019 or COVID-19 pandemic has extensively altered the patterns of human activities globally. It has been directly linked to changes in the environment, particularly the state of air quality. The COVID-19 global pandemic has immediately changed the lives of most, if not all people in its first year of emergence. In the Philippines alone, there are a total of 3,844,708 confirmed cases with 61,221 deaths as of August 3, 2022 (WHO Health Emergency Dashboard, 2022).

The country responded to the COVID-19 threat by enforcing national and local lockdown measures in the effort to hinder the spread of the pathogen. During the quarantine periods, academic institutions suspended classes, government offices ran on skeletal workforce, non-essential businesses were forced to close down, mass transportation was prohibited, and some areas even limited the number of people who can go outside to purchase essentials (Hapal, K., 2021).

This massive shift in anthropogenic activities inadvertently reduced harmful gas emissions into the atmosphere. This includes common air pollutants such as Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Ozone (O_3), and Carbon Monoxide (CO) which are directly and indirectly produced through mobile and stationary sources. Mobile pollution sources, which are mostly on-road motorized vehicles such as buses, jeepneys, cars, trucks, and motorcycles, are greatly cut back because of the mobility suppression. The decreased economic activity consequently reduced processes of stationary sources by lowering demand of some goods and services (Asian Development Bank, 2020).

Studies show significant decline of air pollution in countries like China, Iran, USA, India, and most countries in South America and Europe which had imposed similar quarantine measures (Fan et al., 2020, Shami et al., 2022, Liu et al., 2020, Cooper et al., 2021). In the Philippines, early reports in 2020 based on ground data revealed a drop in air pollution levels following the imposition of enhanced community quarantine. The improved air quality during lockdown raised awareness of the unhealthy levels of air pollutants such as NO_2 pre-lockdown (Cayetano et al., 2020).

Sentinel-5P provides atmospheric measurements with high spatio-temporal resolution used for air quality, ozone & UV radiation, and climate monitoring and forecasting. With visible and UV bands, the Tropospheric Monitoring Instrument (TROPOMI) measures atmospheric concentrations of ozone, carbon monoxide, nitrogen dioxide, and sulfur dioxide.

The analysis of the quarantine periods' effect on the variation of gaseous pollutants is not as straightforward due to other factors that determine their concentration. Therefore, retrievals are also analyzed taking into account the influence of short term meteorological parameters such as ambient temperature and rainfall. Temperature plays a role in the chemical reactions that determine how long gasses stay in the atmosphere. For example, heat can assist in the formation of ground level ozone from oxides of nitrogen (NOx) and volatile organic compounds (VOC) (Mazzuca, et al., 2016). Additionally, the accompanying high pressure creates a stagnant environment because lack of wind impedes pollutant dispersion. This exacerbates the health hazard already imposed by air pollution. Rainfall on the other hand can inhibit formation of ground level ozone by blocking out solar irradiation and washing/breaking it down through moisture (Kang-Shin Chen et al., 2004). Rain droplets also attract aerosol in the atmosphere as it reaches the ground through the process of coagulation effectively clearing the air off these particles (Shukla et al., 2008).

There are four distinct climate types in the Philippines which are characterized by these meteorological factors including humidity: Type I with distinct dry period from November to April, wet season during the rest of the year; Type II where rainfall is evenly distributed throughout the year, with minimum rainfall during December to February or March to May; Type III has only one to three months of dry season either from December to February or March to May; and Type IV with rainfall evenly distributed throughout the year (DOST-PAGASA, n.d.).

This study analyzes the trend of air pollutant concentrations through spaceborne data from January 2019 up to May 2022 over cities in the Philippines representing different climate conditions. The case study provides insights on the effect of quarantine periods and meteorological factors over the course of more than 3 years to the decline and rebound of gaseous pollutants. Lastly, analysis and continuous monitoring of air pollution and the anthropogenic and meteorological factors that affect it can help in nationwide air quality management.

2. METHODOLOGY

2.1 Study Sites

Metro cities representative of each climate type in the Philippines were selected, namely, National Capital Region (NCR), Legazpi City, Metro Cebu, and Davao, of climate types I, II, III, and IV, respectively.

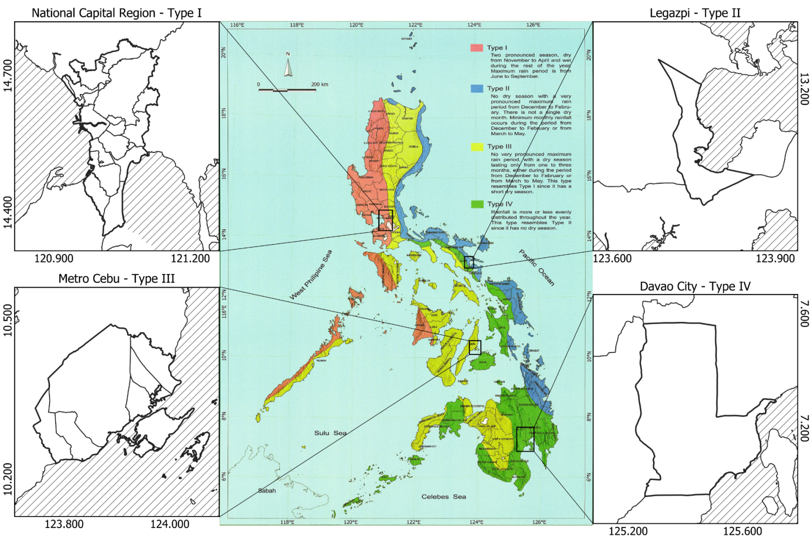

Figure 1. The Philippine Climate Types and Study Sites, NCR, Metro Cebu, Legazpi City and Davao City.

Pandemic lockdowns for each study site were varied in accordance to the area's COVID-19 cases and risks. This has caused implementation of guidelines that ease physical and economic restrictions. Varied severity of community quarantine tiers and alert levels were enacted starting March 2020. Classifications of the lockdown systems are Enhanced Community Quarantine (ECQ), Modified Enhance Community Quarantine (MECQ), General Community Quarantine (GCQ), and Modified General Community Quarantine (MGCQ), with ECQ being the strictest. The following year in September 2021, an alert system was introduced with 5 tiers; 1 with lenient restrictions and 5 with strict protocols. Areas of interests were limited to urban portions of representative cities to focus on sources of anthropogenic emissions near the populace.

2.2 Data Collection and Analysis

Sentinel-5P provides atmospheric measurements with high spatio-temporal resolution used for monitoring air quality, ozone & UV radiation, and climate. Spatial data of NO_2, SO_2, O_3, and CO were collected using Google Earth Engine from the Sentinel-5P Offline collection. The available dataset is processed to level 3 product, with daily coverage of the total vertical column and tropospheric column density data.

To study the effect of meteorology in the air quality, temperature and rainfall data from MODIS Land Surface Temperature/Emissivity Daily and Monthly Products, and the Integrated Multi-satellite Retrievals for GPM (GPM IMERG) Late Run were obtained. Daily data were extracted from January 1, 2019 to May 31, 2022 and were then aggregated to monthly time series per study area. Table 1 summarizes the products gathered for this research.

Table 1. Satellite data products and specifications.

Satellite & Product	Resolution
Sentinel-5P TROPOspheric Monitoring Instrument (TROPOMI), OFFL Collection Nitrogen Dioxide, Sulfur Dioxide, Ozone, Carbon Monoxide	1x1°, daily
MODIS Aqua & Terra, Land Surface Temperature/Emissivity Monthly (MOD11C3)	0.05°, monthly
Global Precipitation Measurement (GPM), GPM IMERG Late-Run (Integrated Multi-satellitE Retrievals for GPM)	0.1°, 30-minute, daily

Monthly air quality conditions through column densities of gas pollutants were subjected to time series analysis to understand the trends of air pollution and impacts of lockdown periods and meteorology in the observed patterns.

3. RESULTS AND DISCUSSION

3.1 Trends of Air Quality during COVID-19 Pandemic

Time series of air quality in terms of NO_2, SO_2, O_3, and CO Vertical Column Density (VCD) are plotted per city with corresponding imposed community quarantine from January 2019 to May 2022. Plots per metro city are shown from Figures 2 to 5.

Strictest lockdown was initialized in NCR starting March 15, 2020 to April 15, 2020; followed by varying community quarantine guidelines from strict to the most lenient. NCR, as the capital of the Philippines, is one of the defined metropolitan areas where activities in the region range from social and economic. Figure 2 shows the gaseous concentrations in NCR alongside quarantine periods.

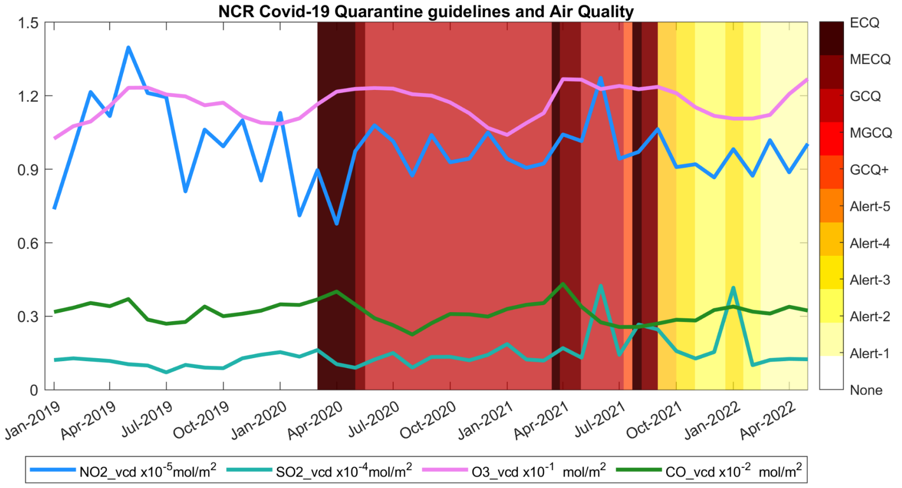

Figure 2. Sentinel-5P air quality measurements in NCR and Quarantine Guidelines.

Sentinel-5P measurements of NO_2 reflect a decrease of 28% from pre-quarantine period, March 2019 to ECQ period, March 2020; and a recorded 48% sudden drop by the first day of ECQ period. This markdown was sustained during the 2nd week of March until the 2nd week of May. Progressing through other quarantine classification with lightened guidelines, the NO_2 emission trend can be observed as increasing, coinciding with the deviations, and values from the previous year. As tiers of community quarantines were introduced from April 1 to June 30, 2022, a 27.3% increase in NO2 concentrations was observed, returning to pre-pandemic air quality as the guidelines ease physical and economic restrictions. For 2021, the emission is shown to have variations yet almost in parallel with 2020's emission. This is highly influenced by decrease in vehicle emissions, and power plants as major sources of NO_2 in urban areas (Department of Energy, 2021). Yearly average in NCR measures 105.6295 umol/m^2, 94.3386 umol/m^2, 98.1340 umol/m^2, 103.2580 umol/m^2 for 2019 to 2022, respectively; highest compared to other metro cities studied by a factor of two. Most recent monthly measurements show a huge spike in NO_2 concentrations and would require further monitoring.

On the other hand, the main sources of SO_2 in the Philippines are volcanic emissions. SO_2 measurements in the capital show a notable increase in June 2021 and January 2022, with 425 umol/m^2 and 416.5 umol/m^2, respectively. This reflects activity from Taal Volcano placed under Alert 3 (Magmatic Unrest) last 2021 and 2022 (Philippine Institute of Volcanology and Seismology, n.d.). Despite this, retrievals during lockdowns have no observed effect.

Maximum total vertical column ozone concentration in NCR measures 0.13 mol/m^2. No difference in levels between 2019 and the pandemic years 2020 and 2021 with yearly averages of 0.1147 mol/m^2, 0.1170 mol/m^2, and 0.1184 mol/m^2, respectively. Yearly carbon monoxide levels also do not vary with average records of 0.0319 mol/m^2, 0.0315 mol/m^2, and 0.0313 mol/m^2 for 2019-2021. Hence, not much direct effect in O_3 and CO is observed due to the imposed guidelines.

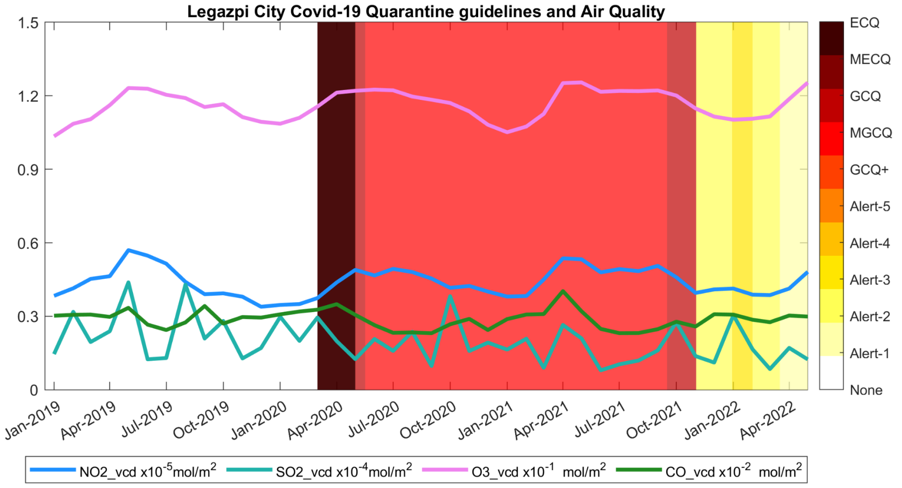

Figure 3. Sentinel-5P air quality measurements in Legazpi City and Quarantine Guidelines.

Figure 3 shows the trace gas trends with the lockdown periods in Legazpi. Imposed lockdowns did not affect NO_2, O_3, and CO in Legazpi City shown in consistent trend with pre-pandemic concentrations. However, Legazpi City is situated near Mayon Volcano which has been active for the past decade. Latest activity was last February 2020 with a reported crater glow which raised its alert level status at a moderate level of unrest. This volcanic activity is reflected in retrieved columnar SO_2 density as wind transports the emissions over the city. SO_2 yearly average in the Legazpi estimates are 234.03 umol/m^2, 212.44 umol/m^2, and 160.40 umol/m^2 for 2019, 2020, and 2021, respectively. Decrease in emissions by 9% in 2020 and by 31% by 2021 are observed as status was lowered from Alert Level 2 (Moderate Level of Volcanic Unrest) to Alert Level 0 (Normal). (Philippine Institute of Volcanology and Seismology, n.d.)

Metro Cebu started with lenient community quarantine then progressed to stricter lockdowns last May 2020. Figure 4 shows the trends of pollutants and quarantine periods imposed in Metro Cebu.

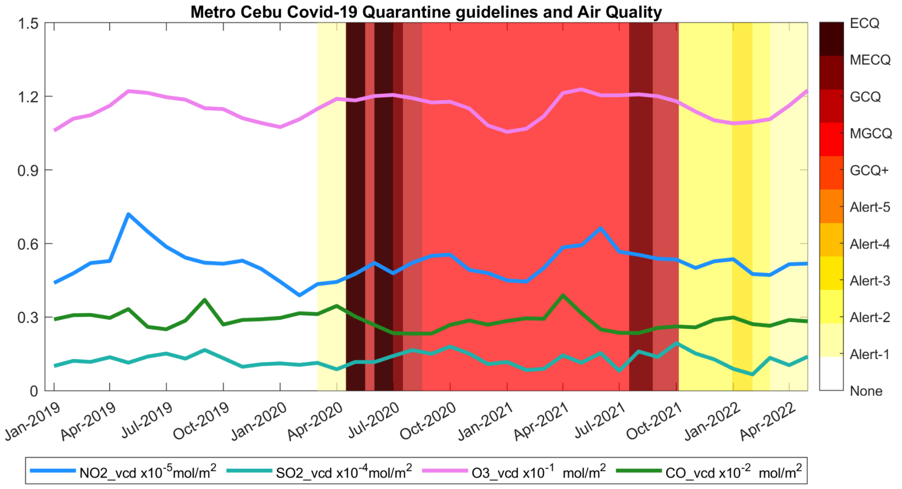

Figure 4 Sentinel-5P air quality measurements in Metro Cebu and Quarantine Guidelines.

Gradual decrease of NO_2 concentration in Metro Cebu can be observed in the pandemic years starting May 2020 coinciding with the imposition of strict lockdowns; with an overall decrease of 11.4% in 2020 versus 2019. As quarantine classification was lightened, only 1.15% difference of NO_2 levels were recorded for 2021 versus 2019; returning to pre-pandemic levels of air quality. Retrieved values of VCD columnar SO_2 are near background levels of < ~400 umol/m^2 but also shows regularity having yearly averages of 126.26 umol/m^2, 128.94 umol/m^2, and 129.43 umol/m^2, for 2019, 2020, and 2021 respectively. O_3 and CO concentrations show no observed effect due to the imposed community quarantines; with average retrievals ranging from 0.1148 - 0.1160 mol/m^2, 0.0280 - 0.0296 mol/m^2 of O_3 and CO, respectively during 2019-2021.

Similar to Metro Cebu, Davao city started with low level lockdown protocols during April 2020 but quickly shifted to stricter measures in May. Figure 5 shows the gas concentrations with the concurrent quarantine periods.

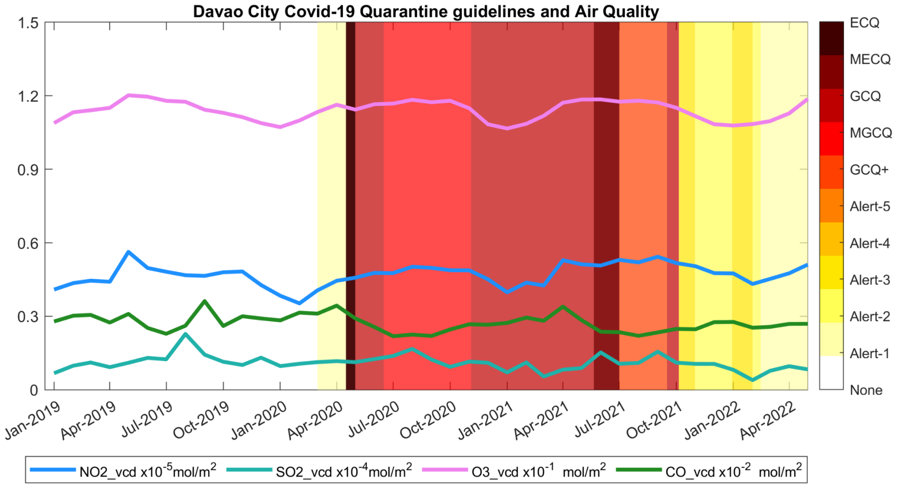

Figure 5 Sentinel-5P air quality measurements in Davao City and Quarantine Guidelines.

NO_2 retrieval in Davao City shows monthly averages for 2020 which are generally lower than all the other months in succeeding years; with a 6.8% average difference versus 2019. SO_2 peaks are observed during 2019 to April 2020 lockdown but overall values are near typical background levels. Decrease over time is observed by 2.4% last 2020 and 14% in 2021. Davao City shows consistent retrieved values of $NO_{2,}$ O_3, and CO during pre-pandemic and quarantine periods with NO_2 concentrations ranging from 45-49 umol/m^2, O_3 concentrations ranging from 0.1141-0.1145 mol/m^2, and CO concentrations ranging from 0.0260 - 0.0280 mol/m^2 during 2019-2022.

3.2 Air Quality, Land Surface Temperature, and Rainfall

The Philippines has four climate types based on rainfall, humidity, and surface temperature. Amount and distribution of these parameters define the two major seasons of the country: the rainy season from June to November, and the dry season from December to May (DOST-PAGASA, n.d.). Study sites are representative of the four climate types, Type I, II, III, and IV represented by NCR, Legazpi City, Metro Cebu, and Davao City, respectively. Satellite based measurements of land surface temperature and rainfall are investigated and related to total vertical column density and tropospheric estimates of trace gasses.

NCR, representative of the climate type I, experiences two pronounced seasons, dry conditions during November to April, and wet conditions for the rest of the year. This is distinguished by LST and rainfall time series with distinct patterns of seasonality; peak temperature records during March to April, while increased rainfall during May to October. Shown in Figure 6 are monthly time series plots of total vertical and tropospheric column density of NO_2, SO_2, O_3, and CO, in parallel with land surface temperature and rainfall measurements.

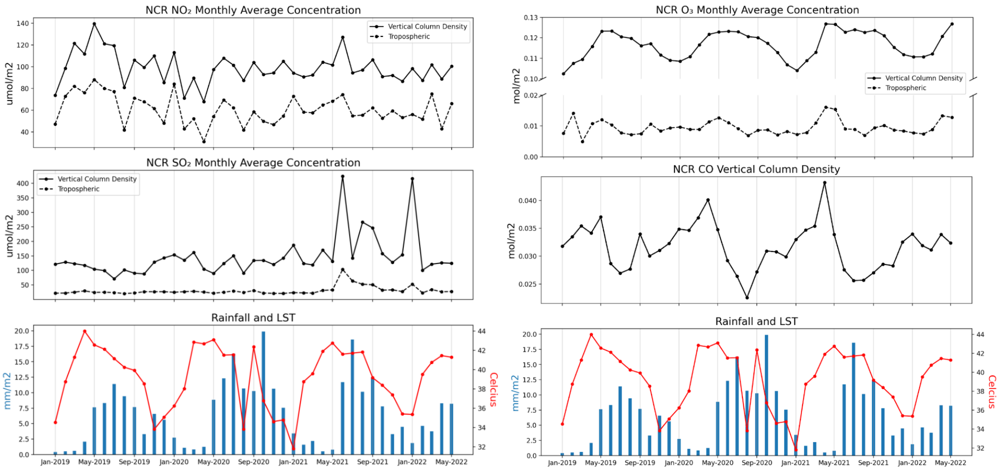

Figure 6. Climate Type I - LST and Rainfall with air pollutants.

NO_2 total VCD and tropospheric column density follow the seasonal trend of temperature which increases during dry months and decreases during wet months. Decrease in NO_2 is concurrent with peak precipitation rates during May to October and dips during the dry cold season of December. This demonstrates the washout effect of rainfall on air pollutants (Guo, L., et al, 2016). The same seasonal trend was observed with O_3 and CO, which depicts increase in emission during dry season, and decrease in wet season. Column densities of SO_2 seem to have no observed changes with regards to the season.

Climate type II, represented by Legazpi City, is characterized by a maximum rain period from December to February with no dry months. In Figure 7, rainfall measurements are almost distributed throughout the year, with minimal rates during the first few months of the year from January to March.

Figure 7. Climate Type II - LST and Rainfall with air pollutants.

Air pollutants show the same behavior as with Type I trends, increasing emissions with temperature, and decreasing patterns demonstrating washout effect by high rainfall values. Coincidentally, high estimates of rainfall are observed during 2020 as the pandemic sets in. With super typhoons Goni (Rolly) and Vamco (Ulysses) bringing heavy rains in November together with the imposed quarantine periods, notable changes are observed in NO_2 and CO retrievals. SO_2, retrievals are too variable to compare with meteorological parameters due to volcanic emissions of Mayon Volcano.

Climate Type III has evenly distributed rainfall with short periods of dry season either during December to February or March to May. Time series in Figure 8 over Metro Cebu shows LST peaks during March to May of 2019 and 2020; progressing to the following years with moderate amounts of precipitation.

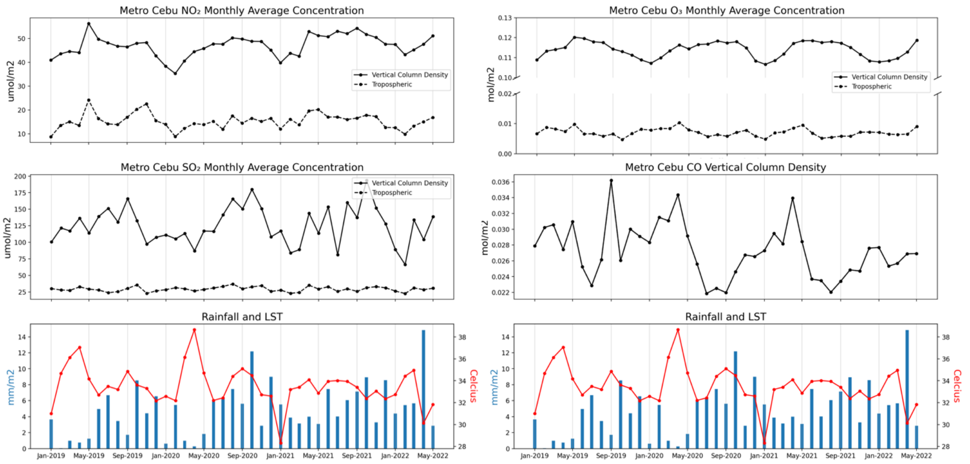

Figure 8. Climate Type III - LST and Rainfall with air pollutants.

Following the meteorological observations, NO_2 shows high concentrations during high temperature months in 2019 and stabilizes its trend with moderate retrievals through the pandemic years, 2020 to present. SO_2, O_3, and CO concentrations show consistent patterns over the years.

Type IV climate type has no dry season and rainfall is evenly distributed throughout the year. Time series records show precipitation to be consistent throughout the year and peak temperatures observed during April to June as shown in Figure 9. Concentrations of air pollutants increase with high temperatures. SO_2 during 2020 is observed to be influenced by high precipitation rates during September to December.

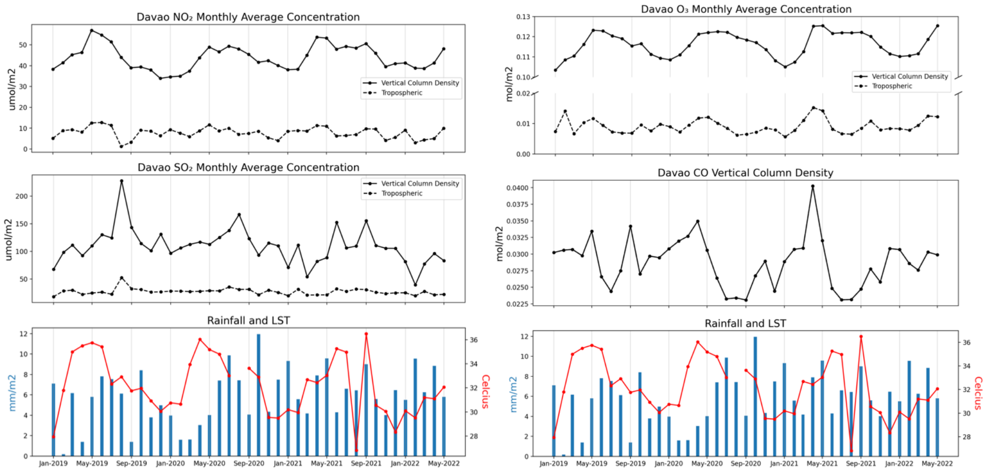

Figure 9. Climate Type IV - LST and Rainfall with air pollutants.

4. CONCLUSION

The effect of COVID-19 pandemic restrictions and meteorological conditions on air quality in the Philippines were studied. Sentinel-5P provided high spatio-temporal resolution measurements which were used in monitoring trace gas concentrations of air pollutants and revealed the observable impact of COVID-19 lockdown for each metro city. Community quarantines and alert levels imposed progressed from the most strict to lenient protocols; and during these times have observed improvements in air quality but gradually showed signs of rebound to pre-pandemic levels.

Decline in NO_2 retrievals were evident in the first months of lockdown impositions, March 2020 to April 2020 in NCR, May 2020 in Metro Cebu, and in overall 2020 emissions for all study sites. These drops are likely influenced by decrease in fuel combustion sources such as vehicle emissions and power plants as major sources of NO_2 in urban areas. Evaluation of NO_2 across study sites show that the average concentration in NCR is 1.9, 2.1, 2.3 times higher than in Metro Cebu, Davao City, and Legazpi City, respectively. In contrast, SO_2 average concentration is highest in Legazpi City due to the nearby active volcano by factors of 1.4, 1.6, and 1.8 compared to NCR, Metro Cebu, and Davao City respectively. SO_2 trends are primarily determined by volcanic activities in the vicinity, i.e Taal Volcano near NCR and Mayon Volcano in Legazpi City. Lastly, O_3 and CO remained consistent with its pre-pandemic retrievals. As years progressed, rebound of emissions were observed starting in 2021, with a yearly average drawing near pre-pandemic levels in 2019.

On the other hand, climate types of study areas are distinguished by rainfall reflected in GPM records, with varying distributions from pronounced period to evenly distributed throughout the year. Together with MODIS LST, with distinct high measurements during March to May. These have influenced the trends and behavior of air pollutants each season. Generally, behavior of air pollutants increases during the dry season of months March to May and decreases in the wet season from June to November following the LST trend. Wet seasons and super typhoons were also distinguished, demonstrating washout effects on air pollutants.

Analysis of air pollutant trends reveal the difference in sensitivity to the change of observed factors. With the imposed quarantine periods, NO_2 and SO_2 concentrations in particular showed significant decline while CO and O_3 were hardly affected. This shows that NO_2 was more reactive with the decrease in emission sources. SO_2 concentration is mainly affected by volcanic emissions which otherwise follow meteorological conditions. Conversely, the pattern of O_3 and CO concentrations closely follow seasonal variation of meteorological factors and were less affected by the sudden decrease in anthropogenic activities. This reinforces that O_3 and CO are more influenced by long standing effects of climate. O_3 concentration is controlled by photochemical processes involving NOx and VOCs while CO concentration is determined by the oxidation of long-lived methane and other hydrocarbons, both dependent on meteorological conditions (Borhani et al. 2021, RNMI, n.d).

Future studies will be conducted to further determine contribution of changes in anthropogenic activities and meteorological conditions with variations in air quality at higher temporal resolution. The weights of each factor will be determined to quantify their influence. Lastly, major emission sources will be identified to establish anthropogenic and natural causes of pollutants.

5. ACKNOWLEDGEMENT

This research is supported by the Satellite Mission Analysis, Planning, Product Enhancement and Development (SatMAPPED) project of the Philippine Space Agency (PhilSA). The authors would also like to acknowledge the technical help of Mr. Michael Angelo Valete and Paul Daniel Ang from the Earth Sciences Space Mission Studies Division (ESSMSD) of PhilSA.

References

Asian Development Bank, 2020. The COVID-19 Impact On Philippine Business. Retrieved August 2020, from https://www.adb.org/sites/default/files/publication/622161/covid-19-impact-philippine-business-enterprise-survey.pdf

Borhani, F., Shafiepour Motlagh, M., Stohl, A. et al., 2021. Tropospheric Ozone in Tehran, Iran, during the last 20 years. Environ Geochem Health.

Cayetano, M., Bagtasa, G., Ramos, R. 2020. Air quality after ECQ far from ‘new normal’ expectations – UPD experts, Retrieved August 2022, from https://up.edu.ph/air-quality-after-ecq-far-from-new-normal-expectations-upd-experts/

Cooper, M.J., Martin, R.V., Hammer, M.S. et al., 2021. Global fine-scale changes in ambient NO2 during COVID-19 lockdowns. Nature 601, 380–387.

Department of Energy, 2020. List of Existing Power Plants, Retrieved September 2022, from https://www.doe.gov.ph/list-existing-power-plants?withshield=1

Department of Environment and Natural Resources, the Philippine Environmental Management Bureau, 2015. National Air Quality Status Report CY 2008 – 2015

Department of Science and Technology - Philippine Atmospheric, Geophysical and Astronomical Services Administration, n.d. Climate of the Philippines, Retrieved August 2022, from https://www.pagasa.dost.gov.ph/information/climate-philippines

Fan, C., Li, Y., Guang, J., Li, Z., Elnashar, A., Allam, M., & de Leeuw, G., 2020. The Impact of the Control Measures during the COVID-19 Outbreak on Air Pollution in China. Remote Sensing, 12(10), 1613.

Guo, L.-C., Zhang, Y., Lin, H., Zeng, W., Liu, T., Xiao, J., … Ma, W. 2016. The washout effects of rainfall on atmospheric particulate pollution in two Chinese cities. Environmental Pollution, 215, 195–202.

Hapal, K., 2021. The Philippines' COVID-19 Response. Journal of Current Southeast Asian Affairs, 40(2), 224–244.

Kang-Shin Chen , Y.T. Ho , C.H. Lai , Y.A. Tsai & Shui-Jen Chen., 2004. Trends in Concentration of Ground-Level Ozone and Meteorological Conditions during High Ozone Episodes in the Kao-Ping Airshed, Taiwan, Journal of the Air & Waste Management Association, 54:1, 36-48.

Liu, S., Valks, P., Beirle, S. et al., 2020. Nitrogen dioxide decline and rebound observed by GOME-2 and TROPOMI during COVID-19 pandemic. Air Qual Atmos Health 14, 1737–1755.

Mazzuca, G. M., Ren, X., Loughner, C. P., Estes, M., Crawford, J. H., Pickering, K. E., … Dickerson, R. R., 2016. Ozone production and its sensitivity to NOx and VOCs: results from the DISCOVER-AQ field experiment, Houston 2013. Atmospheric Chemistry and Physics, 16(22), 14463–14474.

Philippine Institute of Volcanology and Seismology, Retrieved September 2022, from https://www.phivolcs.dost.gov.ph/index.php/taal-volcano-bulletin-menu/

Royal Netherlands Meteorological Institute, n.d. Data Products Carbon Monoxide. Retrieved May 13, 2005, From http://www.tropomi.eu/data-products/carbon-monoxide

Shami, S., Ranjgar, B., Bian, J., Khoshlahjeh Azar, M., Moghimi, A., Amani, M., & Naboureh, A., 2022. Trends of CO and NO2 Pollutants in Iran during COVID-19 Pandemic Using Timeseries Sentinel-5 Images in Google Earth Engine. Pollutants, 2(2), 156–171. MDPI AG.

Shukla, J. B., Misra, A. K., Sundar, S., & Naresh, R., 2008. Effect of rain on removal of a gaseous pollutant and two different particulate matters from the atmosphere of a city. Mathematical and Computer Modelling, 48(5-6), 832–844.

WHO Health Emergency Dashboard, 2022.Philippines: WHO Coronavirus Disease (COVID-19) Dashboard With Vaccination Data, Retrieved August 2022, from https://covid19.who.int/region/wpro/country/ph