ASSESSING THE TRACE GASES IN SUBIC PORT AND ITS RELATIONSHIP WITH SHIP VESSEL COUNTS USING REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM (GIS)

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ABSTRACT: Port regions are the most vulnerable to the pollutants released by ships and the most common methods to assess the air quality in ports are ground monitoring stations or ship emission calculations. In the Philippines, there are approximately 1,200 ports and only a total of 98 air quality monitoring stations. Thus, there is a lack of accurate data on emissions and limited availability of precise methods for tracking the emissions. This study investigates the relationship between ship counts and air pollutant concentrations, specifically, Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), and Carbon Monoxide (CO), in the vicinity of Subic Bay's coastal area. The study utilizes a zoning system based on distance from the shore to examine the relationship of ship counts on Vertical Column Density (VCD) levels of air pollutants. The study area was divided into 6 buffer zones: Zone 1 (0-1 km), Zone 2 (0-2 km), Zone 3 (0-3 km), Zone 4 (0-4 km), Zone 5 (0-5 km), and Zone 6 (0-6 km). Spatial and temporal variability of VCD levels is assessed using hot spots analysis and box plots, covering the period from 2019 to 2021 at 12-day intervals. Correlation coefficients were also calculated between ship counts and VCD levels for each air pollutant, analyzing daily patterns of the week. This analysis is complemented by the inclusion of hotspots to further understand the relationships between ship counts and air pollutant concentrations. The findings revealed that distinct patterns and variations are observed in hotspot clustering and pollutant levels across Zones 1 to 6 and on Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday. The correlation analysis between ship counts and air quality parameters show significant correlations on specific days and zones, indicating a direct relationship between the number of ships and pollutant levels. Zones with high correlation values observe the emergence of hotspots. In contrast, hotspot analysis shows minimal hotspots on the mainland or cold spots in the water regions when there is a significant low or negative correlation. The findings of this study can contribute to maritime regulatory laws and policy making that may help improve the emission reduction plans within maritime ports. With sufficient data such as, daily records of remotely sensed data or other datasets that have same time capture for both parameters and detailed activity within port, the results of the study can be further improved.

1. INTRODUCTION

1.1 Background of the Study

The Philippines have approximately 1,200 ports – both commercial and fishing ports (Philippines Ports | Shipping Companies | Maps and Photos, n.d.). Commercial ports are used for regional and international trading. Among the numerous ports in the country, these are the 5 biggest ports: Port of Manila, Port of Cebu, Batangas International Port, Port of Subic, and Port of Cagayan de Oro (Top 5 Ports in Philippines, 2020). According to a statistical report from PPA, 230,687 ship calls (both domestic and foreign) in total were documented during 2022 and 126,728,765.39 total volumes of cargo handled were recorded. All in all, maritime ports in the Philippines help a lot in boosting the trading industry of the country.

Most air quality monitoring systems in ports use ground monitoring stations to study and regulate the toxic emissions released by shipping vessels. However, in the Philippines, the air quality monitoring stations are lacking in numbers. According to the 2016-2018 National Air Quality Status Report from EMB-DENR, a total of 98 monitoring stations were scattered throughout the country, having the NCR with the highest number of 32 monitoring stations. Meanwhile, in Region 3, where the Subic Port is located, only 7 monitoring stations are established. This lack of monitoring stations makes it difficult to monitor the air quality status of ports in the Philippines. Thus, this study will utilize satellite data to mend the lack of ground stations in maritime ports.

This study can contribute to the limited existing knowledge about the correlation between ship count and air quality. By classifying the data into days of the week, the study can examine on which days may exhibit higher or lower ship traffic which in turn influences the air quality parameters in the port area. Moreover, the results from this study can be used as a basis for maritime policy making that includes emission reduction plans which can be later extended to forecasting of air quality conditions within the port. Lastly, this study can improve the regulatory laws for the maritime industry through available air quality information that can be used for assessing emission levels and population exposure on and nearby the ports.

1.2 Objectives

This project aims to utilize satellite data to analyze the spatial and temporal trends of the maritime industry and its impact on air quality concentrations. Specifically, this study aims to:

1.3.1. utilize sentinel sensors to assess ship counts and trace gases in Subic port;

1.3.2. calculate the ship count and pollutant levels from the coast at different zones; and

1.3.3.investigate the relationship between the number of vessels with the vertical 4 column density(VCD) levels at different zones from the coast on different time intervals.

1.3 Related Literature

According to the Fourth International Maritime Organization (IMO) Greenhouse Gas Study 2020, global shipping generated 1,056 million tonnes of CO_2 in 2018, which was equivalent to about 2.89% of all anthropogenic CO_2 emissions globally. Additionally, using a voyage-based allocation method, international shipping contributed 740 million tonnes of CO_2 to global shipping in 2018 (International Maritime Organization, n.d.). However, lack of accurate data on emissions being released and the availability of only poor methods for tracing the responsible for those emissions to the various nations, traders, producers, consumers, and transport companies involved have both contributed to maritime shipping emissions remaining out of the spotlight and becoming the least of the concerns of the society (Trimmer & Godar, 2019).

Various studies analyze the impact of ship exhaust emissions on air quality in ports using ground air quality monitoring stations. These stations have sensors to measure pollutants like particulate matter, NO_2, SO_2, O_3, CO, and Volatile Organic Compounds. Some sensors are stationary, while advanced methods like Lidar and Differential Optical Absorption Spectroscopy are used for ship plume measurements (Cheng et al., 2019). UAV-based sensors offer an alternative, but they can be costly (Anand et al. 2020). Passive samplers like the Radiello sampler are also employed for cost-effective, long-term air quality monitoring (Prati et al. 2015).

Satellite remote sensing complements ground monitoring by filling spatial gaps. A study in Los Angeles used multi-axis Differential Optical Absorption Spectroscopy (MAX-DOAS) and Fourier Transform Spectrometry (CLARS-FTS) at a high altitude to monitor various pollutants and greenhouse gases throughout the entire basin, despite having only one monitoring location (Stutz et al. 2015).

Based on the studies mentioned above, the study would like to address the lack of accurate data and air quality monitoring stations through remote sensing. Specifically, the study will focus on monitoring the three main air pollutants found in shipping vessel emissions: nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) using Sentinel 5P TROPOMI datasets obtained from Google Earth Engine (GEE). Additionally, the study utilized Sentinel-1 SAR datasets for maritime monitoring in Subic port obtained from the Philippine Space Agency (PSA).

2. MATERIALS AND METHODOLOGY

2.1 Datasets and Materials

Sentinel 5P is the first Copernicus mission devoted to air monitoring. The sole payload of the satellite is the TROPOspheric Monitoring Instrument (TROPOMI) which uses passive remote sensing methods to accomplish its goal by measuring the solar radiation that the earth reflects and radiates at the Top Of Atmosphere (TOA). Data retrieval is supported by Sentinel 5P TROPOMI up to Level 2 data files. The TROPOMI L2 products provide geolocated data on the total column densities of ozone, nitrogen dioxide, carbon monoxide, formaldehyde, methane, and sulfur dioxide, tropospheric column and profile of ozone, as well as information on the index and layer height of aerosols (European Space Agency, n.d.). This study will be focusing on the total column density parameters of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). Philippine Space Agency (PhilSA) is the country's central government agency that focuses on issues and activities related to space science and technology. Included in their responsibilities is to use satellite imagery to map different phenomena happening in the country. PhilSA has a space data dashboard that houses various datasets such as water quality, night lights, air quality, flood maps, etc. For this study, the researchers acquired the marine traffic data from PhilSA (https://philsa.gov.ph/spacedata), in SHP and CSV format, which shows the number and location of the ships on a specific day. PhilSA used the Sentinel-1 datasets to detect ships and create a 12-day interval marine traffic map from 2019 to 2021. In this study, Google Earth Engine (GEE) was utilized to extract Sentinel-5P TROPOMI datasets for the following air quality parameters: Carbon Monoxide, Nitrogen Dioxide, and Sulfur Dioxide. The extracted data was then used to determine the spatial and temporal variation of air pollutants in Subic Bay from January 2019 to December 2021.

2.2 Methods / Processes

2.2.1 Extracting Sentinel 5P TROPOMI

As seen from Figure 1, this study utilized satellite image collections to examine the spatio-temporal distribution of air pollutants. The study gathered 12-day interval satellite images from January 2019 to December 2021, Sentinel 5P TROPOMI datasets of SO_2, 25 NO_2, and CO were obtained from Google Earth Engine (GEE). Since the available data from PhilSA are 12-day interval marine traffic data, 12-day interval satellite images were extracted for the spatiotemporal analysis of the study. The study acquired the total vertical column densities (VCD) of offline Level 3 NO_2 (COPERNICUS/S5P/OFFL/L3_NO_2), offline Level 3 SO_2 (COPERNICUS/S5P/OFFL/L3_SO_2), and offline Level 3 CO (COPERNICUS/S5P/OFFL/L3_CO). Sentinel 5P offers data up to Level 2 (L2) products, however GEE allows the conversion of the products into Level 3 done by the harp convert tool using the bin_spatial operation. This tool also filters the products through the Quality Assurance parameters (Google Earth Engine, n.d.). To extract the datasets, the shapefile of the rectangular bound of the study area covering Subic Port was imported to define the region's limits for the pollutant parameter. Then, the period of analysis will be defined in the filterDate operation which covers the study period from January 2019 to December 2021. Lastly, to download the datasets, code execution in GEE was performed.

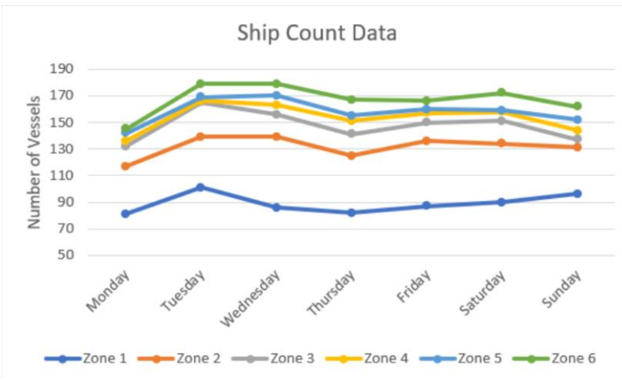

Figure 1. Line Chart of the Ship Count Data per zone on the days of the week

2.2.2 Visualization of Data using Box Plots

To assess the statistical and temporal variations of NO_2, SO_2, and CO data in 12- day intervals, box plots of vertical column density of the air quality parameters were created. A box plot gives fundamental information about the distribution of the datasets by graphically representing the quartiles of a group of numerical data. It displays a fivenumber summary consisting of the minimum, first quartile, median, third quartile, and maximum (Praveen et al., 2017). The box plots depict the range of VCD values for each zone across different air quality parameters, using R-studio to generate the visual 26 representation of variability.

2.2.3 Spatial Analysis of VCD Levels and Ship Locations

In order to have a cohesive spatial analysis, the temporal resolution of ship location and VCD levels of each air pollutant needs to be similar. Since the temporal resolution of ship location data from PhilSA is every 12 days, maps of the 12-day interval VCD of SO_2, NO_2, and CO were created from the extracted TIFF files from GEE to examine the spatial trend over the course of the study period.

To determine the trends in hot spots, cold spots, and ship locations, the Hot Spot Analysis tool in ArcGIS Pro was utilized. The Getis-Ord Gi* statistic is determined for every feature in a dataset by the Hot Spot Analysis tool. The resulting z-scores and p-values show you where geographic clustering of characteristics with high or low values occurs. This tool operates by examining each feature considering its surrounding features (ArcGIS Pro, n.d.). A feature must both have a high value and be surrounded by other high-value features in order to be a statistically significant hotspot (Grigoraș & Urițescu, 2018). Raster images were converted into points which were then used for the hotspot analysis. The hot spots were analyzed along with the maritime traffic data, wind speed and wind direction data. Hotspot maps of 12-day interval from January 2019 to December 2021 and aggregate VCD values for Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday were generated in this study.

2.2.4 Correlation Analysis Between VCD Levels and Number of Ships

The zonation plays a crucial role in this study as it examines the relationship between VCD levels and ship locations at different distances from the coast. To create buffer zones and extract their corresponding 12-day average VCD levels, QGIS will be utilized to outline the coast over Subic port. Then, the Buffer tool in QGIS will be used to create buffer zones from the coast at 1-kilometer intervals. Six zones were created: Zone 1 (0-1 km from the coast), Zone 2 (0-2 km from the coast), Zone 3 (0-3 km from the coast), Zone 4 (0-4 km from the coast), Zone 5 (0-5 km from the coast), Zone 6 (0-6 km from the coast). Using the Raster Pixels to Points, the extracted TIFF files of the 12-day average VCD levels were converted to point shapefiles. Then, using the join attribute by location tool in QGIS, the pixel values of the air quality parameters within each zone were extracted.

XLSTAT Pearson correlation coefficient was used to generate the correlation matrix to determine the relationship between the number of ships and each of the air quality parameters (NO_2, SO_2, CO). The researchers used the 12-day interval VCD level per zone interval and the 12-day maritime traffic data from PhilSA. Additionally, the data was grouped based on the days of the week. For each zone interval, a correlation matrix between the VCD level and number of ships will be generated. After running the test, an assessment was made to determine the relationship between the number of ships and the air pollutants 31 in each zone interval.

2.3 Results and Discussion

2.3.1. Carbon Monoxide (CO)

Figure 2a shows the variability of CO VCD data for each zone. The zone with the highest variation is Zone 4, which has a value of 2.90E-05 mol/m^2 and a range of 0.03 mol/m^2. On the other hand, the zone with the lowest variation is Zone 1, with a value of 2.84E-05 mol/m^2 and a range of 2.84E-05 mol/m^2. Additionally, the peak average CO VCD value is observed in Zone 1, with a value of 4.59E-02 mol/m^2, while the lowest average CO VCD value is found in Zone 3, with a value of 2.00E-02 mol/m^2.

Figure 2b displays the box plots representing the average CO VCD levels per zone for each day of the week. In general, Tuesday exhibits the highest variation, with a value of 4.76-05 mol/m^2 and a range of 0.03 mol/m^2. Conversely, Wednesday shows the lowest variation, with a value of 1.16E-05 mol/m^2 and a range of 0.01 mol/m^2. Furthermore, Tuesday also records the highest peak average CO VCD value of 0.05 mol/m^2, while the lowest average CO VCD value of 0.02 mol/m^2 is also observed on Tuesday. The zones with the highest variation vary across the days of the week: Zone 2 on Sunday, Zone 3 on Monday and Tuesday, Zone 4 on Friday and Saturday, Zone 5 on Wednesday, and Zone 6 on Thursday. Conversely, the zones with the lowest variation differ as follows: Zone 1 on Monday, Thursday, and Sunday, Zone 2 on Wednesday and Friday, and Zone 6 on Tuesday and Saturday.

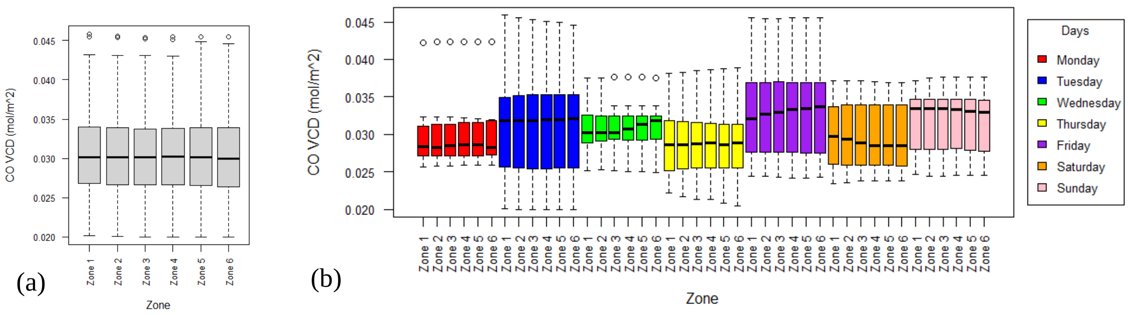

Figure 2. Average CO concentration for each zone in (a) and Average CO concentration for each day of the week in (b)

Figure 3 reveals distinct patterns in hotspot occurrence of carbon monoxide based on the day of the week. The aggregate of vertical column density (VCD) data shows that on Tuesdays, Sundays, and Thursdays, the majority of hotspots are observed on land. Conversely, on Mondays and Fridays, the hotspots predominantly appear in the water area. On Wednesdays and Saturdays, the hotspots exhibit a more specific spatial distribution. Specifically, on Wednesdays, the aggregate of hotspots is concentrated on the southwest portion of the study area, which corresponds to the water area. This suggests a localized hotspot concentration in that particular region. On Saturdays, the aggregate of hotspots is observed on the northern part of the study area, covering both land and water. This indicates a broader hotspot distribution that extends to the land area.

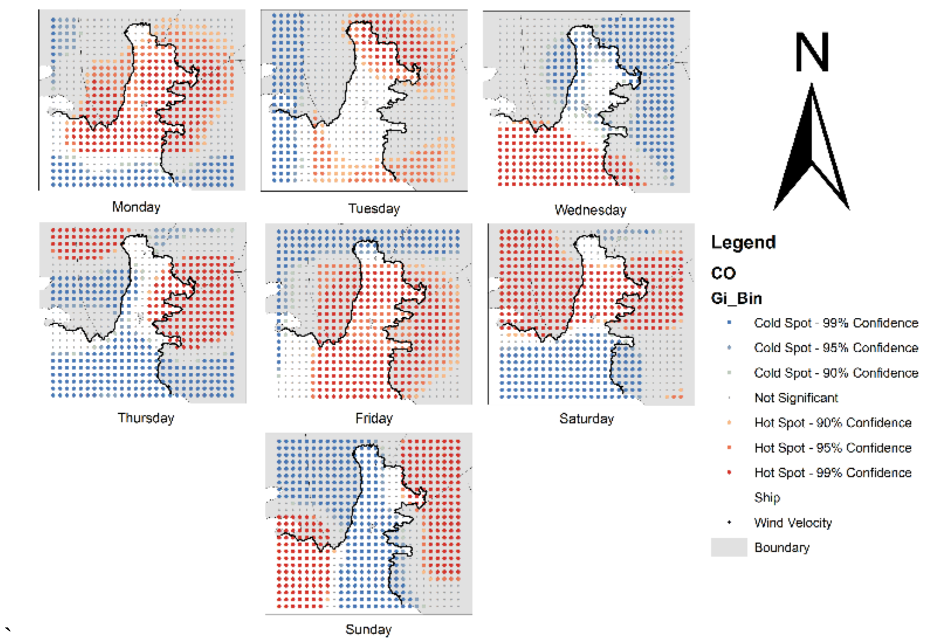

Figure 3. Carbon Monoxide Hotspot Analysis on Each Day of a Week

2.3.2. Nitrogen Dioxide (NO_2)

Figure 4a shows the variability of NO_2 VCD data for each zone. The zone with the highest variation is Zone 1, with a value of 2.06E-10 mol/m^2 and a range of 8.70E-05 mol/m^2. On the other hand, the zone with the lowest variation is Zone 6, with a value of 1.93E-10 mol/m^2 and a range of 8.40E-05 mol/m^2. Additionally, the peak average NO_2 VCD value is observed in Zone 1, with a value of 1.05E-04 mol/m^2, while the lowest average NO_2 VCD value is found in Zone 4, with a value of 1.71E-05 mol/m^2.

Figure 4b depicts the box plots illustrating the average NO_2 VCD levels per zone for each day of the week. In general, Wednesday exhibits the highest variation, with a value of 2.97E-10 mol/m^2 and a range of 5.31E-05 mol/m^2. Conversely, Saturday shows the lowest variation, with a value of 5.91E-11 mol/m^2 and a range of 2.80E-05 mol/m^2. Additionally, the peak average NO_2 VCD value is observed on Friday, with a value of 1.02E-04 mol/m^2, while the lowest average NO_2 VCD value of 1.71E-05 mol/m^2 occurs on Sunday. The zones with the highest variation differ across the days of the week: Zone 1 on Tuesday, Thursday, and Saturday, Zone 3 on Monday, Friday, and Sunday, and

Zone 6 on Wednesday. Conversely, the zones with the lowest variation vary as follows: Zone 1 on Wednesday, Friday, and Sunday, Zone 4 on Saturday, and Zone 6 on Monday, Tuesday, and Thursday.

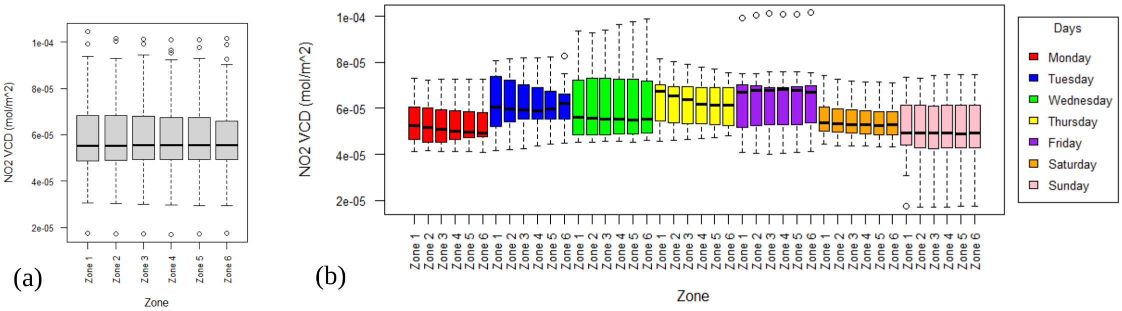

Figure 4. Average NO_2 concentration for each zone in (a) and Average NO_2 concentration for each day of the week in (b)

Figure 5 shows that the aggregate of nitrogen dioxide values indicates specific hotspot behavior and spatial distribution for each day. On Mondays, the hotspots mainly appear on land, indicating a concentration of events in the land region. While on Thursdays, Saturdays, and Sundays, the aggregate of hotspots is observed in the northern region of the study area, encompassing both land and water near the seaport. This suggests a spatial concentration of hotspots in this specific region. The presence of the seaport could be a contributing factor to the hotspot occurrence in this area during these days. On Tuesdays, Wednesdays, and Fridays, the hotspots mostly lie on the water area; this indicates a potential influence of water-related factors on hotspot formation and distribution during these days.

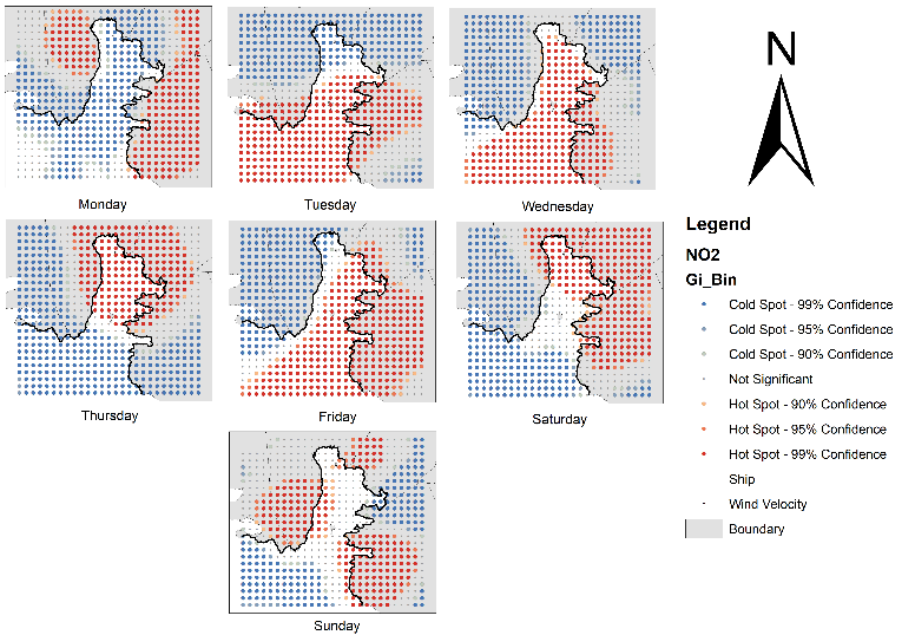

Figure 5. Nitrogen Dioxide Hotspot Analysis on Each Day of a Week

2.3.3. Sulfur Dioxide (SO_2)

Figure 6a shows the variability of SO_2 VCD data for each zone. The zone with the highest variation is Zone 1, with a value of 2.06E-10 mol/m^2 and a range of 8.70E-05 mol/m^2. Conversely, the zone with the lowest variation is Zone 6, with a value of 1.93E-10 mol/m^2 and a range of 8.40E-05 mol/m^2. Additionally, the peak average SO_2 VCD value is observed in Zone 1, with a value of 1.05E-04 mol/m^2, while the lowest average SO_2 VCD value is found in Zone 4, with a value of 1.71072E-05 mol/m^2.

Figure 6b displays the box plots representing the average SO_2 VCD levels per zone for each day of the week. In general, Tuesday exhibits the highest variation, with a value of 7.56E-08 mol/m^2 and a range of 1.13E-03 mol/m^2. Conversely, Sunday shows the lowest variation, with a value of 6.92E-09 mol/m^2 and a range of 2.97E-04 mol/m^2. Moreover, the peak average SO_2 VCD value is observed on Tuesday, with a value of 9.27E-04 mol/m^2, while the lowest average SO_2

VCD value of -4.20-04 mol/m^2 occurs on Friday. The zones with the highest variation differ according to the day of the week: Zone 2 on Sunday, Zone 3 on Monday and Tuesday, Zone 4 on Friday and Saturday, Zone 5 on Wednesday, and Zone 6 on Thursday. Conversely, the zones with the lowest variation vary as follows: Zone 1 on Monday, Thursday, and Sunday, Zone 2 on Wednesday and Friday, and Zone 6 on Tuesday and Saturday.

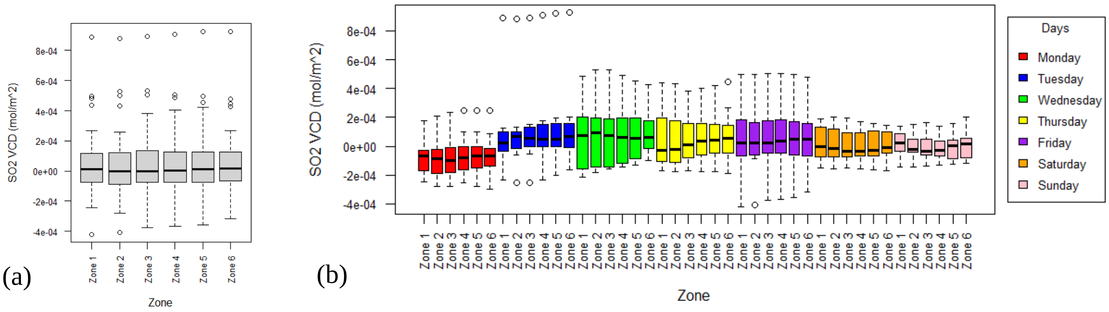

Figure 6. Average SO_2 concentration for each zone in (a) and Average SO_2 concentration for each day of the week in (b)

Figure 7 shows the behavior of hotspot clustering of sulfur dioxide based on the different days of the week. The aggregate of vertical column density (VCD) data shows that on Monday the hotspots are observed on the majority of the water region while on Sundays, Saturdays, and Tuesdays, the hotspots predominantly lie on the land area. On the other hand, the aggregate of hotspots is observed in the middle region of the water zone on Wednesdays, Thursdays, and Fridays.

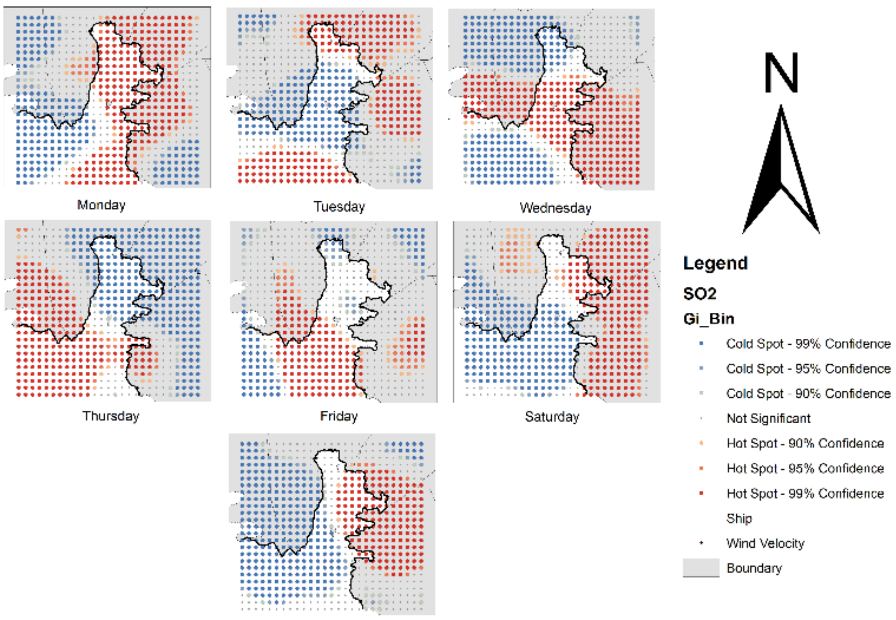

Figure 7. Sulfur Dioxide Hotspot Analysis on Each Day of a Week

3. CONCLUSION

The spatial and temporal analysis of CO, NO_2, and SO_2 concentrations in Subic port from January 2019 to December 2021 were determined using remote sensing and GIS techniques, specifically using datasets from Sentinel 5P TROPOMI for VCD levels extraction and ship locations from PhilSA. Generated box plots showed significant variation in the amounts of air pollutants – Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), and Sulfur Dioxide (SO_2) – throughout various time periods and zones. These results highlight specific days when the levels were noticeably high or low and show the temporal variability in air pollution concentrations across several zones. Such insights help us better understand the patterns and dynamics of the air quality parameters in the examined region and can be very useful for managing and reducing air pollution in the future.

The analysis of hotspot clustering for CO, NO_2, and SO_2 reveals spatial patterns and temporal variations. CO hotspots cluster near the coast while NO_2 hotspots are concentrated near ship points and the northern part of the study area. SO_2

hotspot clustering shifts from water areas in 2019 to land in 2020. In 2021, no consistent pattern is observed. There is no specific directional pattern in hotspot clustering for CO, NO_2, and SO_2. Hotspot analysis based on the day of the week shows varying spatial distributions. Carbon monoxide hotspots are on land on Tuesdays, Sundays, and Thursdays, and on water on Mondays and Fridays. Nitrogen dioxide hotspots are mainly on land on Mondays and in the northern region of the study area on Thursdays, Saturdays, and Sundays. Sulfur dioxide hotspot clustering varies by day, with Monday hotspots on water and Sunday, Saturday, and Tuesday hotspots on land.

Relationship between ship counts and carbon monoxide parameters reveals significant positive correlations on specific days and zones, indicating a direct relationship between the number of ships and pollutant levels measured by VCD. The direct relationship between the two parameters is supported by the hotspot analysis of the aggregated values for Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, and Sunday. When there is a positive correlation on a zone, the clustering of hotspots is observed on that zone. Conversely, if significant low or negative correlations are observed, hotspot analysis shows coldspots on the water region and majority of the hotspots are seen on the land region. However, on certain days of the week, despite having a low correlation, hotspot analysis shows a clustering of hotspots on the water region and vice versa. This suggests that other pollution sources and spatial distribution patterns may contribute to hotspot distribution.

For further studies, it is recommended to utilize daily records of remotely sensed data or other datasets that have same time capture for both air quality parameters and maritime information to have a more accurate analysis and to address the lapses between the 12-day intervals. Moreover, future researchers may consider adopting the zoning approach with equal ranges employed by Lv et al. (2018). This would allow the zones to be independent of each other, enabling the utilization of Analysis of Variance (ANOVA) to evaluate the significant differences between the zones. However, in order to conduct this analysis, it is advised that they expand the study area to encompass larger zone ranges. It is 76 also recommended to consider other relevant factors, such as ship type records in the port and ship emission factors of different ship types, precipitation, and a more detailed wind parameter analysis. Lastly, the researchers suggest further looking into the activities occurring during the time period in both water and mainland regions for better analysis of the results.

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