Government COVID-19 Responses and Subsequent Influences on NO_2 Variation in Ayutthaya, Thailand

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***Abstract*— The control of economic activities by governments for the purpose of minimizing COVID-19 spread influenced atmospheric conditions. Satellite-based technology is promising to monitor these changes and even non-specialists in geospatial analysis can use it through cloud-based open platforms. This study aims to give scientific interpretation on the causes of the atmospheric changes based on these governmental controls on human activity. The nitrogen dioxide (NO_2) levels were monitored in Ayutthaya Province in Thailand in an urban area including industrial zones during January 1 to April 30, 2020. An analysis was conducted with Google Earth Engine by using four datasets including NO_2 data from Sentinel-5P. The mean value of NO_2 density in 2020 decreased 12.5% compared with that in 2019. The closure of industrial facilities by the government seemed to be a key cause of the phenomena. The decline was statistically tested and resulted in a significant difference between the two periods. As the new daily cases decreased to single digits, the difference became non-significant from May 1, 2020. Single timeseries analysis on NO_2 density change enabled visualization of the brief impact of responses and policies made by the government and subsequent economic activities; however, further atmospheric and industrial activity data are required for further assessment.**

Keywords*— *COVID-19, air quality, Google Earth Engine, government response, Thailand

I. Introduction

The first case of COVID-19 in Thailand was reported on January 13, 2020 [1]. It was listed as the first case outside China. As of June 1, 2020, there have been 3,082 total cases with 57 deaths reported in Thailand [2]. Central and local governments have been responding to the situation and making policies to prevent further infection spread. The impacts of those initiatives are revealed not only in spread mitigation but also in changes to economic activities and the subsequent environmental changes, either adversely or positively [3]. For example, [4] found an abrupt decline of nitrogen dioxide (NO_2) over China after the outbreak of COVID-19, which indicates that restriction of economic activities worked. Because various countermeasures were also conducted by Thai central and local governments, a similar NO_2 reduction is likely to have occurred in Thailand. This study aims to provide interpretations of the environmental impact of the COVID-19 responses, with a focus on atmospheric changes in NO_2 in Ayutthaya Province. The province has several major industrial zones as shown in Fig. 1, such as Rojana Industrial Park (IP) – one of the largest industrial zones in Thailand, Bang Pa-In, and Ban Wa (Hi-Tech) Industrial Estates (IEs) where air pollutant control is highly considered.

In Thailand, Department of Disease Control (DDC), Ministry of Public Health has been taking main responsibilities and measures against COVID-19. It is possible to see the prompt response of the country from the establishment of the Emergency Operation Center by the DDC immediately after the identification of the outbreak on January 4 [5]. COVID-19 has been declared as the 14th most dangerous communicable disease by the Ministry, and become under the Communicable Disease Act, B.E. 2558 since March 1, 2020. Several events had been canceled such as the mini marathon, Red Cross fair, and Songkran Festival (i.e., Thai New Year). Following the instructions from the central government, the Ayutthaya government also announced closing service businesses, karaoke, video game arcades, massage parlors, health centers, fitness centers, boxing arenas, cockfighting arenas, golf courses, and driving ranges [6]. After the emergency decree was announced by the central government on March 26, the provincial government also strictly followed the instructions. The first issue of the Declaration of and Emergency Situation in the country had 15 measures: (1) prohibition on entering at-risk areas with ongoing local transmission, (2) closure of at-risk areas of infection, (3) nationwide lockdown, (4) prohibition of hoarding, (5) prohibition of assembly, (6) prohibition of dissemination of false reports and rumors of COVID-19

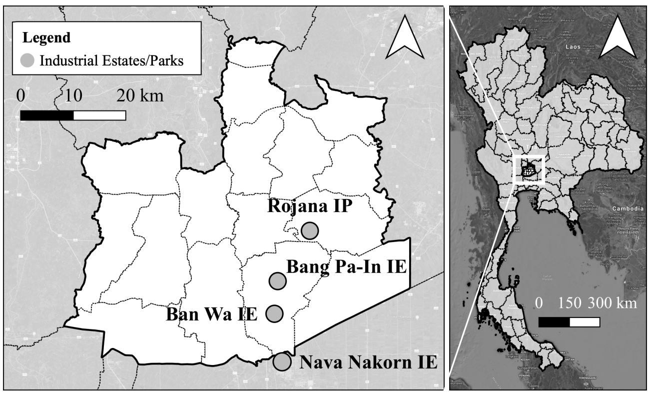

Fig.1. Study area; Ayutthaya province Thailand

outbreaks, (7) precautionary measures, (8) measures for people with special needs, (9) measures for leaving the country, (10) measures for maintaining order, (11) measures for disease prevention, (12) policy for some venues opening with permission, (13) recommendations for traveling to other provinces, (14) recommendations for organizing permitted activities, and (15) penalties and enforcement [2].

In Ayutthaya Province, several additional services were closed including golf clubs, theaters, spas, and yoga centers. Inter-provincial checkpoints were also established. In late March, the Ayutthaya government extended the closure to restaurants, department stores and malls, dine-in areas in convenience stores, markets and weekend markets, beauty and hair salons, Buddha amulet centers, exhibition centers, animal spas and salons (except animal clinics), and nursery schools and childcare facilities (except hospitals). The Government also strictly enhanced the policies and procedures for industrial zones and nearby residences and dormitories. The governor requested all industrial zones to follow these instructions: (1) check the temperature of employees before they enter the shuttle, check that they wear face masks, and provide a suitable distance between seats; (2) have staff to clean all the seats in the vehicles; and (3) provide alcohol gel or spray.

In terms of electricity use, it was reduced by 11,102.22 million units (6.36%) in April 2020 compared to 2019 [7]. The Provincial Electricity Authority described the probable causes to include the closure of hotels and department stores as well as the reduced production at some automotive factories, which caused the steel factories to also reduce their operations. By comparing the data month by month [7], the differences between 2020 and the previous year were +4.66% in January, +1.31% in February, −1.82% in March, and −3.26% in April.

II. Government Responses and Atmospheric Impact

Government responses and policies influence economic activities, and the impact appears in a variety of forms. By using appropriate sensing techniques, the intensity of activity and the arising impacts can be understood in detail. A satellite-based remote sensing technology is an ideal means to assess those changes. Reference [8] monitored spatiotemporal changes of the internal heat field of iron and steel factories by Landsat-8 Thermal Infrared Sensor data to evaluate their production conditions. Reference [9] monitored the changes in world NO_x pollutant concentrations by using high resolution nitrogen dioxide data and found that local emission control efforts resulted in a decrease in NO_2 in some cases. Although scholars have studied economic activities and subsequent impact on air quality, influences of timeseries governmental responses and policies against COVID-19 on air quality are not sufficiently revealed. This study thus contributes to further understanding of the issue by providing a specific case study with powerful yet concise analytic methodology. Because previous studies have shown high degrees of sensitivity with changes in with economic activities, NO_2 was selected instead of other chemicals such as sulfur dioxide, carbon monoxide, and photochemical oxidants.

A. *Change of nitrogen dioxide density*

The Google Earth Engine (GEE) was adopted to analyze the NO_2 density change. GEE is cloud-based platform, which combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities [10]. Four types of data were used: (1) Offline Nitrogen Dioxide (OFFL_NO2) of the Sentinel-5 Precursor to obtain NO_2 data, (2) Global Administrative Unit Layer to set the geographical boundary of analysis, (3) Moderate Resolution Imaging Spectroradiometer (MODIS), Land Cover Type (MCD12Q1) to identify urban areas including industrial zones, and (4) map data (Google, CNES/Airbus, and Maxar Technologies) to validate the extracted urban areas. To analyze visualized images and timeseries data comparisons of NO_2 density in 2019 and 2020, an analysis was conducted using the flow shown in Fig. 2. Further details of the process are as follows:

1) Visual comparison of NO_2 density in 2019 and 2020:

- Select the band, '*NO2_column_number_density*' from OFFL_NO2 and set target duration by considering high new daily cases in 2020; from January 1 to April 30 in both 2019 and 2020.
- Calculate mean value of their NO_2 density, and set visualization parameters: cutoff – do not show values lower than 0.00001, minimum and maximum values of visualization at 0.00001 and 0.0001, respectively, and palette with the following six colors: *black*, *blue*, *purple*, *cyan*, *green*, *yellow*, and *red*.
- Mask the visualization area as the boundary of Ayutthaya Province obtained from GAUL with the name equal to '*Phra Nakhon Si Ayudhya*'.

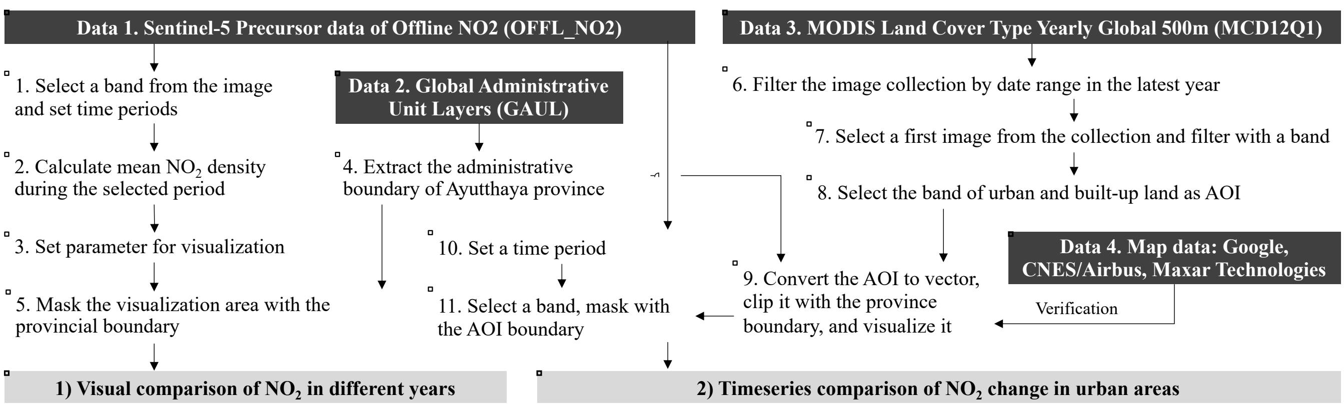

Fig. 2. Flow of the proposed method (GEE code available at 'http://bit.ly/ICASYMP2021GEE')

2) Timeseries comparison in urban areas:

- Filter the image collection of MCD12Q1 by date range in the latest year, filter the first image from the collection, and select the band, '*LC_Type1*', which is the classification of the Annual International Geosphere–Biosphere Programme.
- Clip the image by the classification of '*Urban and Built-up Lands*', value 13 of '*LC_Type1*' Class Table. Then set it as the area of interest (AOI).
- Convert the AOI to a vector, mask the converted image by the boundary of Ayutthaya province, and verify it by Map data: Google, CNES/Airbus, Maxar Technologies.
- Set a time period of OFFL_NO2 from April 1, 2019 to July 23, 2020, select the band '*NO2_column_number_density*', and clip with the AOI.

B. Numerical test and verification

First, the visualized NO_2 densities in 2019 and 2020 were compared to interpret the spatial change tendencies by taking land cover classification into account. Second, the significant difference in numerical values of NO_2 densities was assessed by paired-sample t-test to analyze the timeseries change of NO_2 density. The test was conducted in R statistical computing software, and the evaluated values were exported in .csv format from GEE. Third, government responses and policies described in previous sections, were verified through the NO_2 change based on a chronological approach.

III. Results and Discussion

The mean values of NO_2 density during January 1 to April 30 in both 2019 and 2020 are visualized in Fig. 3. The NO_2 density is higher in the class of '*Urban and Built-up Lands*' of MCD12Q1, whereas it was lower in the classes of '*Croplands*', '*Savannas*', and '*Grasslands*'. Moreover, it is clear that the NO_2 density in 2020 is notably lower than that in 2019; there are three dense spots observed in both years: (1) northern side of Nava Nakorn IE, which has manufacturing factories and apartment and condominium complexes, (2) Rojana IP and parts of the central area of Ayutthaya city, and (3) the northeast area of the province where the steel, iron, and cement factories are located. The densest area in 2020 was at Rojana IP, with a density of 1.14e4 mol/m^2 which had declined from 1.29e4 mol/m^2 in 2019. '*Urban and Built-up Lands*' of MCD12Q1 seemed to represent actual land cover accordingly as shown in Fig. 4 and covers IP and IE, and other urban areas in the province.

Industrial zones – recognized as a key source of nitrogen oxide and other atmospheric material emission – account for 25.4% of the urban area, and approximate areas of 24.0 km^2 (Rojana IP), 3.8 km^2 (Ban Wa IP), 3.3 km^2 (Saha Rattana Nakorn IE), and 3.1 km^2 (Bang Pa-in) [11, 12] out of a total urban area of 134.6 km^2.

The timeseries comparison of NO_2 density change in the urban area (including IP and IE) with the government responses and policies issued is shown in Fig. 5. There was a difference observed in NO_2 density in 2019 and 2020 for the period of January 1 to April 30 (paired $t = 4.908$, df = 116, $p < 0.001$); however, no significant difference was observed from May 1 to July 23 (paired $t = -0.524$, df = 78, $p = 0.602$). The difference in the NO_2 density mean value in the former period was 12.5% − decreased from 1.19e4 mol/m^2 in 2019 to 1.04e4 mol/m^2 in 2020, and a 1.7% difference observed in the latter period. The NO_2 density in 2020 remained relatively lower than in 2019 and showed different change tendencies, even before issues of any particular responses and policies from the government. After the facility closure instructions were first issued on March 20, the NO_2 density dropped and was then maintained at a low level with little fluctuation until almost the end of April, as additional second and third instructions were issued.

The abrupt decline of NO_2 density on March 11 seems to be relevant to the COVID-19 situation because the number of daily new cases started increasing in Thailand at that time. In the same manner, the test result of no significant differences in NO_2 density between 2019 and 2020 after April may be because at the end of April the case numbers decreased to single digits and economic activities started to return to normal. Even though there was no direct significant relevance between the government responses or policies and the single index of air quality, analysis on NO_2 density change would be able to picture brief economic circumstances which is influenced by government activities against COVID-19. Furthermore, this result showed a further research gap relating to the mandatory orders issued from the government. If they do not have legal binding force or strong initiatives to control economic activities, there will be no major reduction of activities and NO_2 will be maintained at high levels unless voluntary restrictions occur.

IV. Conclusion

COVID-19 has greatly changed our society and its impacts have been analyzed from various research fields. However, the influences of government responses on economic activities and subsequent impacts are not clearly

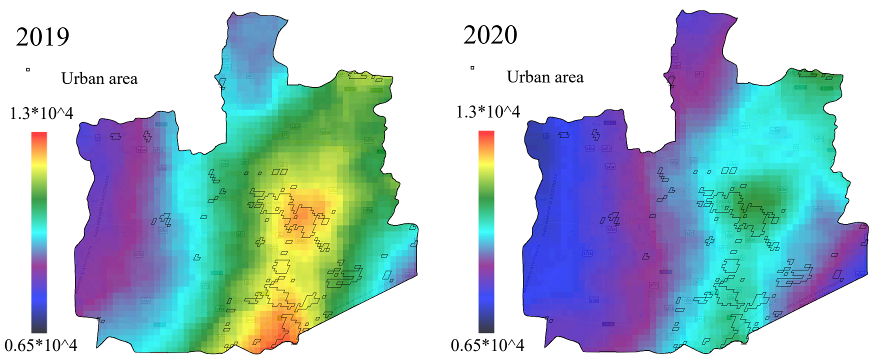

Fig. 3. NO_2 density comparison in 2019 and 2020 in Ayutthaya Province in Thailand

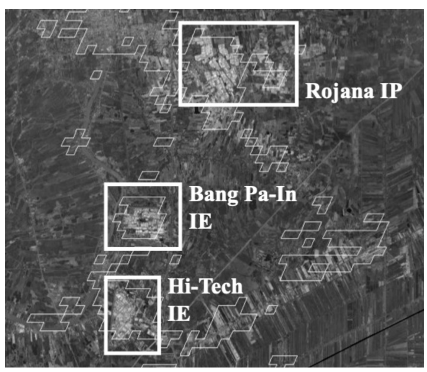

Fig. 4. Verification of urban and built-up areas

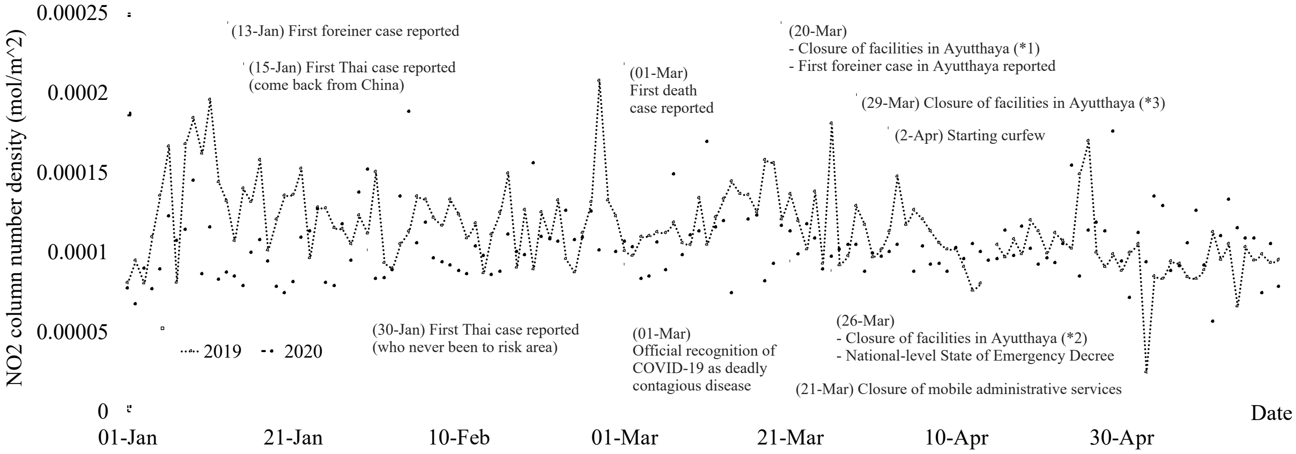

Fig.5. A series of government responses and policies against COVID-19, and comparison of NO_2 changes in 2019 with 2020
(*1) Service shops, karaoke, video game arcades, massage parlors, health centers, fitness centers, boxing arenas, cockfighting arenas, (*2) Sport grounds, golf courses and driving ranges, childen's playgrounds, theaters, spas, yoga centers, (*3) restaurants, department stores, shopping malls, community malls (except supermarkets), dine-in areas in convenience stores, markets and weekend markets, beauty salons, hair salons, Buddha amulet centers, exhibition centers, animal spas and salons (except animal clinics), nursery schools and child care facilities (except hospitals)

understood. Thus, to provide a specific case study, this research focused Ayutthaya Province in Thailand and analyzed the atmospheric change in NO_2 during the COVID-19 of spring 2020. Subsequently, the variations of NO_2 carefully derived based on the land cover classification of MODIS, were interpreted based on consideration of the government responses and polices in a chronological manner. The satellite-based approach using GEE was adopted with four types of data: (1) NO_2 data from Sentinel-5 Precursor; (2) Global Administrative Unit Layer; (3) Lan d cover data from MODIS; and 4) map data from Google, CNES/Airbus, Maxar Technologies. As a result, this study revealed the following findings:

a) The mean value of NO_2 density in '*Urban and Built-up Lands*' in 2020 decreased 12.5% compared with that of 2019 and Rojana IP showed a higher NO_2 density than residential and city central areas in 2020.

b) Statistical differences of NO_2 density between 2019 and 2020 were observed during January 1 to April 30, whereas no significant difference was observed from May 1 to July 23, after the peak in the case numbers.

c) Single timeseries analysis on NO_2 density change has limitations in clarifying the influence of governmental responses and policies on atmospheric impact but does enable the determination of simple correlations.

For further study, additional data should be considered that include not only atmospheric material but also supplemental data such as people flow and actual operation data for industrial zones including individual company to understand the specific influences of government responses on environmental changes. Moreover, the comparison analysis with social networking services such as Twitter may provide further insights [13].

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