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Article

Influential Factors on Aerosol Change During COVID-19 in Ayutthaya, Thailand

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Abstract. Various interventions were made by the Thai government to prevent the COVID-19 spread by controlling socioeconomic activities, but the effectiveness of these interventions and other factors have not yet been fully clarified. Thus, this study aims to provide further scientific evidence on those potential factors which affect the socioeconomic activities changes during the pandemic, by using spatial analysis on atmospheric composition. By taking Phra Nakhon Si Ayutthaya Province, Thailand as the case area. Results of the government's COVID-19 measures and statuses of industries were compared with changes in aerosols, including PM 2.5 which was analyzed by Google Earth Engine with nine open datasets including meteorological and hydrological factors. The analysis revealed that the aerosol index in ueban area of the province decreased at 28.03% in 2020 compared in 2019. Besides, PM 2.5 drastically decreased from March 2020, even without the influence of wind speed which as the highest causal relationship, and kept low level compared with previous years. The reason of the tendency would be explained that other than government interventions including national-level state of the emergency decree, reduction of factories' activities at Rojana Industrial Park and reduction of the number of tourists had significant influence to reduce the mean value of PM 2.5.

Keywords: COVID-19, PM2.5, Google Earth Engine, Government interventions, Thailand.

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1. Introduction

In response to the unprecedented epidemic of Coronavirus disease (COVID-19), the Thai government has implemented various interventions and measures to control the spread of the disease. The first case of COVID-19 in Thailand was reported on January 13, 2020 [1]. It was listed as the first case outside China. Subsequently, the pandemic spread within Thailand, and as of June 1, 2020, the number of infected people totaled 3,082 and the number of deaths rose to 57 [2]. In response to this serious situation, the Thai government has taken serious measures to collect itself to prevent the further spread of infection. These measures are, in other words, to restrict socioeconomic activities by reducing human contact. It has been found that changes in atmospheric composition can provide some indication of the economic activity that has been adversely or positively affected by those government interventions [3]. For example, [4] analyzed the significant decrease in nitrogen dioxide level caused by COVID-19, and resulted that this was due to the government's suppression of economic activities. Similarly, in Thailand, various interventions have been implemented to curb economic activities and prevent the spread of infectious diseases [5], so it should be possible to examine the effects of interventions and other factors by analyzing changes in atmospheric composition, including nitrogen dioxide. Therefore, this study aims to provide new insights into the factors that influence changes in socioeconomic activities under the influence of coronaviruses, including government interventions and measures, through spatiotemporal analysis that takes into account hydro-meteorological observation data that influence changes in atmospheric composition. Phra Nakhon Si Ayutthaya Province (Ayutthaya), Thailand, is selected as a case study area since it has varieties of economic activities of society, truism, and industry which would result in providing insights from diverse perspectives how those activities have been affected by COVID-19 pandemic as well as controlled by central and provincial governments' interventions.

Due to the spread of the coronavirus infection, various events, including Songkran Festival which is known as New Year's Day, have been cancelled in Thailand. Following the central government's response, Ayutthaya Province has also taken measures to restrict the operation of service businesses that involve close contact with people to prevent the spread of the disease: these services include karaoke, video game arcades, massage parlors, health centers, fitness centers, boxing arenas, cockfighting arenas, and training centers. Furthermore, at the time the central government declared the emergency decree on March 26, 2021, the province also followed. The initial declaration of emergency has a total of 15 constraints; Prohibit entry to dangerous places, including areas where infectious diseases are spreading; close down areas where infectious diseases are spreading; lock down throughout the country; prohibit gatherings; advise against movement to other provinces; recommend and authorize implementation of activities; recommend and implement penalties [2].

In addition to the restrictions imposed nationwide, Ayutthaya Province has been targeted for several additional industries, including golf courses, movie theaters, and sports, fitness, and health-related facilities. In late March, the coverage was further expanded to include the following facilities and services: food services such as restaurants; department stores, shopping malls, and indoor eating places in convenience stores; weekend markets; beauty-related services for people and animals; and childcare facilities, excluding hospitals. The Ayutthaya government has also enacted and implemented strict measures to prevent the spread of infection in industrial complex and surrounding residential areas and dormitories. The following actions were requested to the industrial complex: check the body temperature of all employees before getting into a shuttles, disinfect seats, wear a mask, keep a enough distance between seats in a shuttle, and from workers where many employees are working together [6].

2. Factors Influences a Change in Atmospheric Composition During COVID-19

Since COVID-19 is the unprecedented pandemic and governments are responsible to take countermeasures to control the infection spread through various interventions to control socioeconomic activities even without knowing effectiveness and results of those actions. Various studies have been conducted to elucidate the effects of government intervention in preventing the spread of infections and the factors behind the related changes in socioeconomic activities [7, 8, 9]. Atmospheric conditions including density of pollutant materials, thermal temperature, or land cover change clearly reflect situations of socioeconomic activities and growth. Spatiotemporal analysis with earth observation data, which can be used globally, is a promising approach for understanding the atmospheric component changes. For example, reference [10] used high-resolution Earth observation data to analyze changes in the concentration of nitrogen dioxide compounds around the world. As a result, the study found scientifically that the closure of environmentally inefficient factories and vehicle emission regulations contribute to the decrease in the concentration of nitrogen dioxide. Atmospheric changes in relatively in short period can be also observed which enable us to understand specific efficiency of government interventions. Reference [3] assessed the efficiency of strong measures - traffic control and temporary shutdown of polluting industries - initiated by local authorities towards the 2008 Olympic and Paralympic Games in Beijing through tropospheric NO2 column observations. The research found that approximately 60% of NO2 reduction above Beijing during the Olympic period; the strong measure influences reductions of NO2 also at surrounding cities of Tianjin and Shijiazhuang at 30%, and Shijiazhuang at 20%, respectively. Although, the government interventions function appropriately to control economic activities, causal relationship is still not clearly understood; what kind of government interventions or other factors influence specifically on to what type of socioeconomic activities. In that regards, specific socioeconomic activities also should be monitored to assess how the interventions restrict target activities. Reference [11] quantitatively assessed the activity conditions of iron and steel factories by monitoring spatiotemporal changes in the internal heat field of the plants, which was obtained from Landsat-8 Thermal Infrared Sensor. This research makes it possible to monitor and assess operational condition of factories without visiting the site or to contact person in charge of the factory operation.

Characteristics of government interventions for controlling socioeconomic activities during COVID-19 is unique compared to previous literatures since types of interventions – e.g., travel restriction, curfew, and state of the emergency – are different from general restriction of environmental protective measures such as air pollutant emission, shutdown factories, and temporary traffic control. Besides, various interventions are made in relatively short period of time for anticipating quick outcomes to prevent spreading infections. In that context of the pandemic, reference [4] revealed abrupt decline of nitrogen dioxide tropospheric vertical column density in China since COVID-19 prevailed. Notable finding is that the decline can be initiated by the Chinese government's actions: the announcement of the first report in each province and the province's lockdown. This research enables to assess efficiency of government interventions not only at the study area but also for other countries and region since NO2 density can be monitored all over the world by remote sensing technology.

In addition to the previous studies, this research aims to contribute to further understanding on factors which influences on economic activities during COVID-19 including government interventions by adopting a methodology that is very powerful, yet highly accessible. Furthermore, this study will also focus on atmospheric composition other than nitrogen dioxide, which has been the main target of previous studies, to examine the factors that influence changes in socioeconomic activities.

3. Materials and Methods

Ayutthaya Province, the case area, is shown in Fig. 1. The province is the former capital of the Kingdom of Thailand and has an active tourism industry, as well as several major industrial complex in Thailand including Rojana Industrial Park (IP), Bang Pa-In, and Ban Wa (Hi-Tech) Industrial Estates (IEs). There are three outputs derived to understand an efficiency of government interventions against COVID-19 outbreaks through controlling socioeconomic activities: "Visual comparison of aerosol index", "Timeseries comparison in urban areas", and "Factors influences mean PM2.5 change during COVID-19" through controlling socioeconomic activities". The authors anticipate providing generalized and less challenging methodology so that not only professionals who possess specialized knowledge and skillset to conduct analytical approaches with specific datasets but also people who are not familiar with geospatial data analysis can utilize. To that end, the Google Earth Engine (GEE) was adopted. GEE is cloud-based platform, which combines a multi-petabyte catalog of satellite imagery and geospatial datasets with planetary-scale analysis capabilities [12]. Aerosol was focused on this

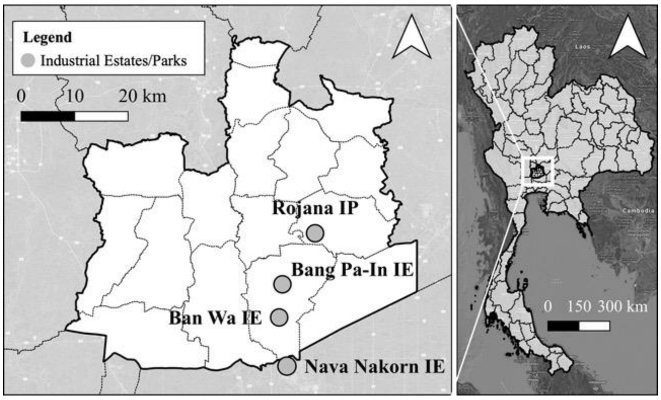

Fig. 1. Ayutthaya Province, Thailand.

Table 1. A series of datasets used for analyzing influential factors on aerosol change during COVID-19.

Dataset	Abbreviation	Type	Purpose
1. Sentinel-5P: Offline UV Aerosol Index	UVAI	Image collection	Aerosol
2. Global Administrative Unit Layers	GAUL	Table	Administrative boundary
3. MODIS Land Cover Type Yearly Global	MCD12Q1	Image collection	Land cover classification
4. ERA5-Land hourly	ECMWF	Image collection	Wind speed and direction, temperature, air pressure
5. Climate Hazards Group InfraRed Precipitation	CHIRPS	Image collection	Precipitation
6. Global Land Data Assimilation System	GLDAS	Image collection	Humidity
7. Copernicus Atmosphere Monitoring Service	CAMS	Image collection	PM2.5
8. Satellite imagery	SI	Image	Verification of land use
9. COVID-19 situation	GI	Text	Government interventions

study since it well represents and reflect human economic and social activities. Besides, atmospheric components tend to be influenced by meteorological conditions as well as ground activities. These conditions were considered for the analysis of efficiency of government interventions. Nine types of data were used as shown in Table 1: (1) Sentinel-5P:Offline UV Aerosol Index to assess aerosol intensity distribution and change, (2) Global Administrative Unit Layers (GAUL) to set the geographical boundary of analysis, (3) Moderate Resolution Imaging Spectroradiometer (MODIS), Land Cover Type (MCD12Q1) to identify urban areas including industrial zones, (4) ERA5-Land hourly, ECMWF climate reanalysis, to obtain, air temperature, pressure, wind speed, and wind direction (5) Climate Hazards Group InfraRed Precipitation (ECMWF), to obtain precipitation, (6) Global Land Data Assimilation System (GLDAS), to obtain humidity, (7) Copernicus Atmosphere Monitoring Service (CAMS) Global Near-Real-Time, to obtain PM 2.5, (8) satellite imagery (Google, CNES/Airbus, and Maxar Technologies) to validate the extracted urban areas, and (9) COVID-19 situation to summarize government interventions against COVID-19 to control human social and economic activities. A detailed analytical flow is described below and shown in Fig. 2:

3.1. Visual Comparison of Aerosol Index Density

Aerosol was adopted as a case atmospheric component in this study. The value is calculated as index which is defined by European Space Agency as a qualitative index indicating the presence of elevated layers of aerosols with significant absorption [13].

- Select the band named '*absorbing_aerosol_index*', the Aerosol Index (AI), from the UVAI image collections, and the period to be analyzed is set to January 1 to July 31 in 2019 and 2020.
- Calculate the AI density for both years and set the parameters of the visualization as follows: cutoff equals to 3.5E-05, minimum and maximum values are 3.5E-05 and 8.2E-05, respectively, and the colors to be used in the palette, in the order black, blue, purple, cyan, green, yellow, and red.
- Select the provincial boundary of Ayutthaya Province named '*Phra Nakhon Si Ayudhya*' from the table data of GAUL and mask the visualization of AI index distribution.

3.2. Comparison of Time Series Changes in Aerosols

There are three processes: first one is to extract urban area of Ayutthaya Province, as an Area of Interest (AOI), which includes industrial estates and parks and convert the boundary of areas into compatible format for calculation, the second is to identify and calculate time series change of atmospheric components, and third is to select meteorological parameters which significantly influences change of the air pollutant components.

3.2.1. Area of Interest (AOI) setting:

- Select the first image from the image collection of MCD12Q1 and select the class table "LC_Type1".
- Set the Area of Interest (AOI) by clipping the selected image with 'Urban and Built-up Lands' which is the value of 13 in the class table.
- To verify the AOI with the map data provided by Google, CNES/Airbus, Maxar Technologies, convert AOI to a vector, and mask it with the boundary of Ayutthaya Province.

3.2.2. Dataset preparation

- Air temperature, pressure, wind speed and direction are selected from the image collection of ECMWF. The former two components are selected from the bands of "*temperature_2m*" and "*surface_pressure*", respectively. The latter two were calculated by a trig function from values in the bands of "*u_component_of_wind_10m*", wind speed in a west-east direction, and "*v_component_of_wind_10m*", in a south-north direction. The band name "*precipitation*" of CHIRPS is used for precipitation, and the band "*Qair_f_inst*" of GLDAS is for humidity.
- Together with the values of PM2.5 which uses the band of "*particulate_matter_d_less_than_25_um_surface*" of CAMS, all bands' data were filtered with the time period from "2017/01/01" to "2019/12/31"
- The all-filtered data is then clipped by the geometry of AOI and the time series value is exported by CSV format for further numerical analysis.

3.2.3. Statistical analysis

Density of atmospheric components including aerosol tends to be influenced by hydrological and meteorological conditions rather than socioeconomic activities controlled by government interventions. To take the impact into account, following steps were adopted.

- Correlation between time series change of mean PM 2.5 and each atmospheric condition is analyzed at each year from 2017 to 2019. Since components of atmospheric conditions correlated each other, e.g., the higher precipitation the higher humidity, partial correlation analysis was adopted to eliminate those effects on change of mean PM 2.5. Subsequently, multiple regression analysis is used to consider causes of mean PM 2.5 changes.
- Time series change of mean PM 2.5 and meteorological factors with which have significant correlation are drawn into chart format.

3.3. Factors Influences Mean PM2.5 Change during COVID-19

First, distributions of mean AI in urban areas of Ayutthaya Province in 2020 and 2019 are visualized to

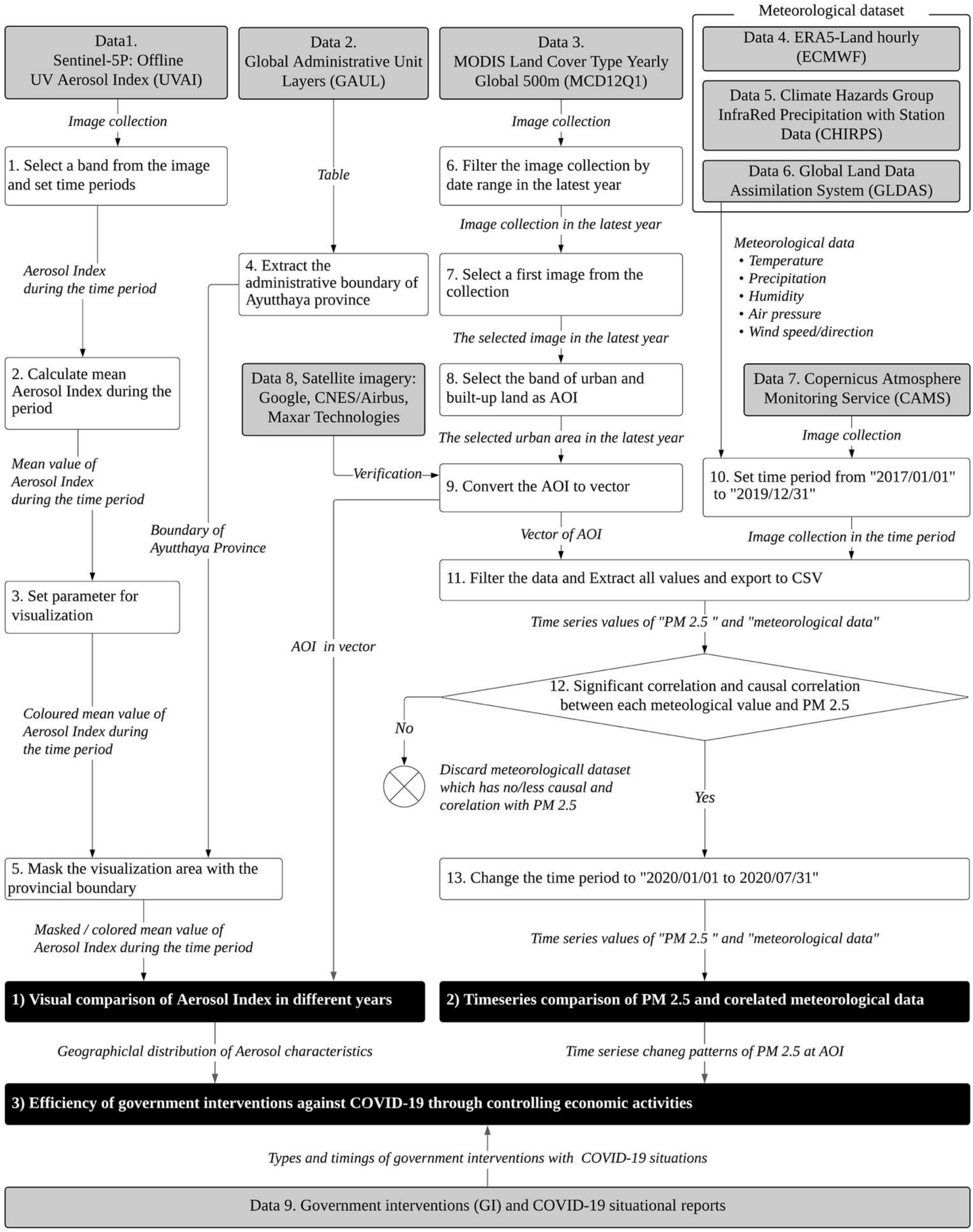

Fig. 2. Analytical flow of the study.

understand the tendency of spatiotemporal changes. Second, time series changes in PM2.5, one of the compositions of aerosols, are statistically analyzed by paired-sample t-test to confirm significant differences among selected year. Third, the factors influencing changes in atmospheric composition of PM 2.5, including government interventions and situations of COVID-19, are discussed based on the numerical results of the spatial analysis and the survey results. Meteorological factors are also considered to detail causes of mean PM2.5 change. Interview was also conducted with the Director of Tourism Authority of Thailand (TAT) Phra Nakhon Si

Ayutthaya Office in March 2021 to understand tourism situations in the study area.

4. Result

4.1. Visual Comparison of Aerosol Index Density

The visualization results of the mean AI in 2019 and 2020 are shown in Fig. 3. It was confirmed that the class table, "*Urban and Built-up Lands*" of the MCD12Q1 adequately represented the actual urban areas and industrial complex in Ayutthaya Province. Industrial complex, one of the main sources of air composition substances, account for about 25.4% of the urban area in Ayutthaya Province; the total urban area of the province is 134.6 km², Rojana IE is 24.0 km² (17.8%), Ban Wa IE is 3.8 km² (2.8%), Saha Rattana Nakorn IE is 3.3 km² (2.5%), and Bang Pa-in IE is 3.1 km² (2.3%) [14, 15]. In common with both years, AI values were found to be higher in "*Urban and Built-up Lands*" and lower in "*Croplands*", "*Savannas*", and "*Grasslands*". Also, the value of AI at the urban area in 2020 is 28.3% smaller than in 2019. Two areas with high AI values identified: Rojana IP and some parts of Ayutthaya city, and north of Nava Nakorn IE.

4.2. Timeseries Comparison in Urban Areas

The value of PM 2.5 and all meteoritical factors: air temperature, pressure, precipitation, humidity, wind speed and wind direction, were filtered with the geometry of AOI, the urban area of Ayutthaya province, and the period 2017 to 2019. Results of correlation analysis is shown in Table 2. Wind speed has relatively higher correlation with the AI ($r=0.518$, $t = 19.764$, $p < 0.001$). Other factors were appeared to be less significant including air pressure which was rated in the second most corelated ($r=0.126$, $t = 7.024$, $p < 0.001$). Result of multiple regression analysis is shown in Table 3. As same as the result of correlations analysis, wind speed rated highest causal relation ($t = 19.764$, $SE < 0.003$, $p < 0.001$) followed by air pressure ($t = 4.128$, $SE < 0.001$, $p < 0.001$). Other three factors of precipitation, air temperature, and humidity were resulted in similar causal relation with the mean value of PM 2.5.

4.3. Efficiency of Government Interventions

The timeseries comparison of mean PM 2.5 change and air pressure in the urban area of Ayutthaya province, including industrial complex with the government interventions and announcements issued are shown in Fig. 4 (a) with the time series change of humidity. There was a notable decline observed in mean PM2.5 in 2020 compared to other years, especially for the period of March 1 to July 31; with 2019 (paired $t = -8.102$, $df = 152$, $p < 0.001$), 2018 (paired $t = -17.151$, $df = 152$, $p < 0.001$), and 2017 (paired $t = -15.308$, $df = 152$, $p < 0.001$). The mean value of PM 2.5 density in the period in 2020 was 5.83e8, and significantly declined from 2017, 2018, and

Table 2. The result of correlation analysis of PM2.5 and meteorological and hydrological factors.

	PM2.5	PC	TMP	HUM	AP	WS
PM2.5	1.00	-0.10	-0.12	-0.12	0.13	-0.52
PC	-0.10	1.00	-0.21	0.26	-0.14	-0.21
TMP	-0.12	-0.28	1.00	0.08	-0.32	-0.16
HUM	-0.11	0.26	0.08	1.00	-0.55	-0.21
AP	0.13	-0.14	-0.32	-0.55	1.00	-0.21
WS	-0.52	-0.21	-0.16	-0.21	-0.21	1.00

Table 3. The result of multiple regression analysis of PM2.5 and meteorological and hydrological factors.

	Std. Error	t value	Pr (>|t|)	
PC	3.92E-04	-3.39	7.32E-04	***
TMP	1.39E-03	-3.82	1.44E-04	***
HUM	1.138	-3.77	1.75E-04	***
AP	1.16E-05	4.13	3.95E-05	***
WS	3.32E-03	-19.8	2.70E-74	***

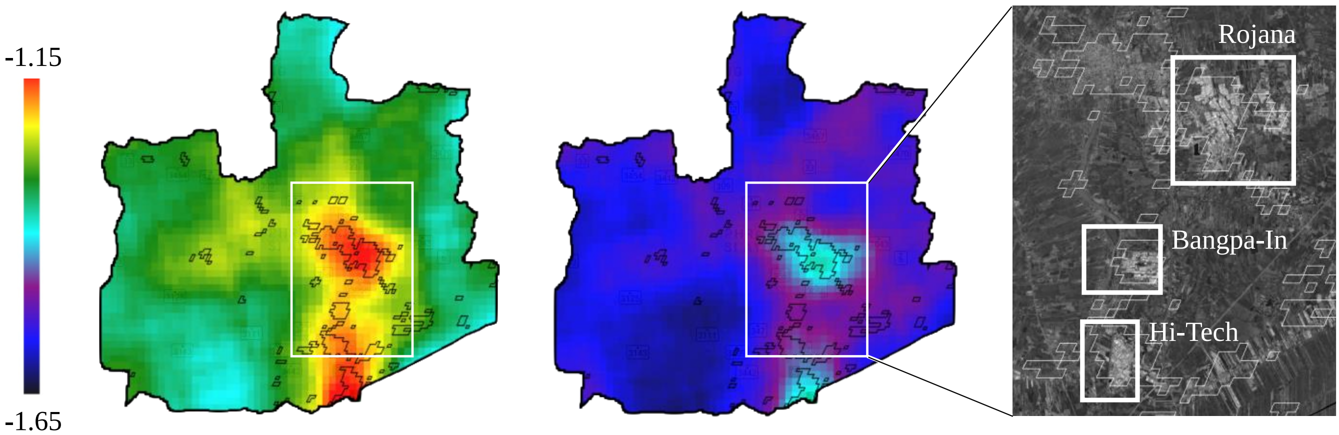

Fig. 3. Aerosol Index comparison in 2019 and 2020 in Ayutthaya Province in Thailand with the locations of industries.

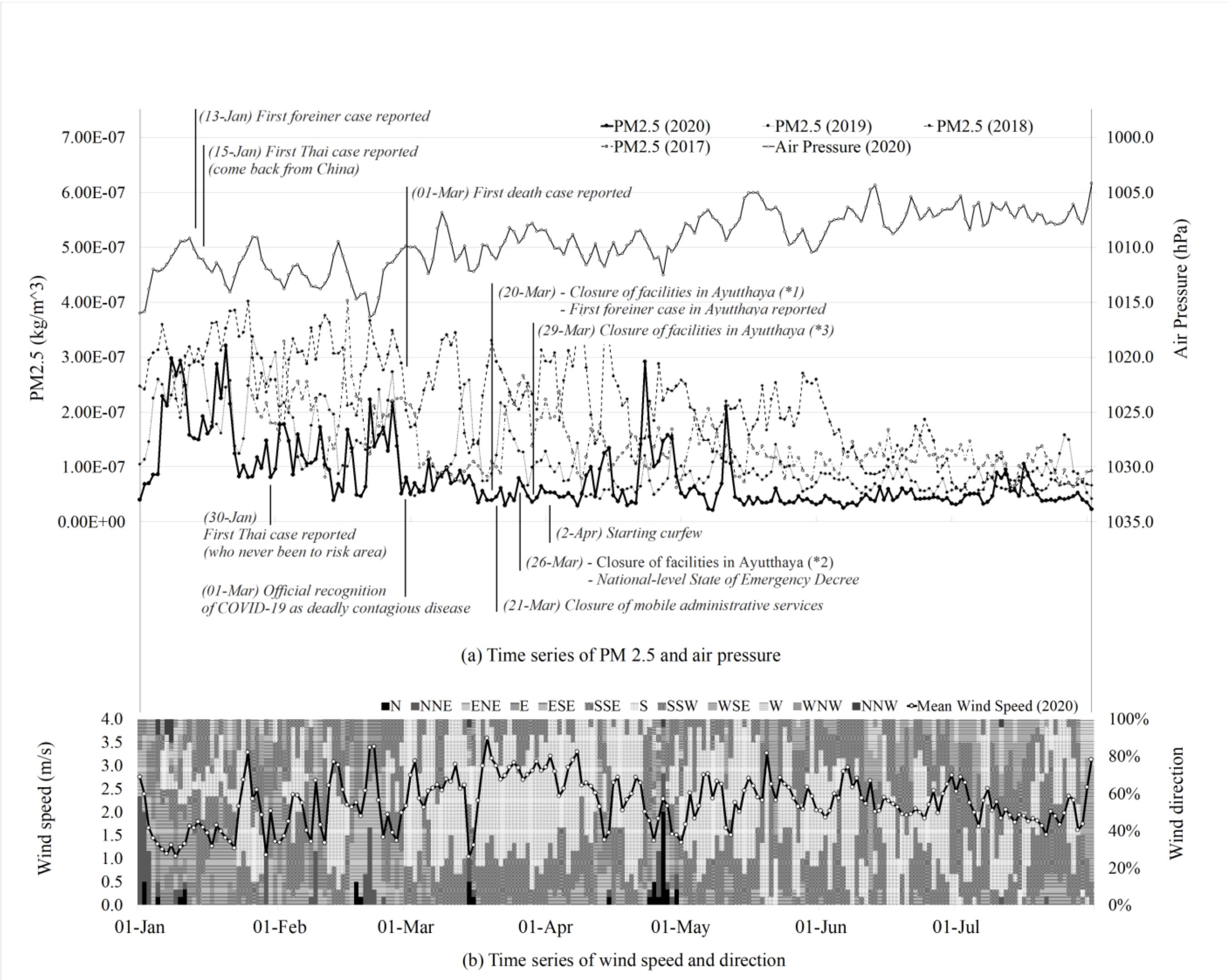

Fig. 4. Time series change of mean PM 2.5 in from 2017 to 2020 with other meteorological factors.

2019 at 35.14%, 66.88%, and 53.43%, respectively. 2020 showed lower mean PM 2.5 compared to 2019. Besides, even before the government declared a state of emergency and other stringent measures were issued, the time series value in 2020 showed a tendency to maintain notably low compared to other years. A day before official recognition of COVID-19 as deadly contagious disease, and first death case report, the mean PM 2.5 density dropped and was then maintained at a low level with some fluctuation during early April to early May.

Wind speed and its direction at each day is also shown in Fig. 4 (b). Tendency of wind direction was that it flows from eastern – East (E), east-southeast (ESE), and east-northeast (ENE) – and a bit of northern (North (N), north-northwest (NNW), and north-northeast (NNE) – from the beginning of January to March and be dominant by southern wind – south (S), south-southwest (SSW), south-southeast (SSE) – until about June and subsequently wind from western – West (W), west-southwest (WSW), and west-northwest (WNW) – increases. Wind speed showed stronger correlation with the mean value of PM 2.5 as derived from statistical analysis in previous section. The higher speed of wind flows the less mean value of PM 2.5 becomes.

The mean PM2.5 dropped drastically on January 20. This tendency seems to be the same with previous years especially 2019, yet differences was that the value in 2020 did not bounce back to the higher values afterward while other years did. The same tendency was observed on March 26. There were no major government interventions issued such as the national-level state of emergency decree nor curfew instructions. The wind which has higher causal correlation with the mean value of PM 2.5 has less different between 2020 and 2017 to 2019, in both January to February, and March to July; 2020 to 2019 (paired $t = -0.851$, $df = 58$, $p = 0.199$) and (paired $t = -2.483$, $df = 152$, $p = 0.007$), to 2018 (paired $t = 3.025$, $df = 58$, $p = 0.002$) and (paired $t = 1.528$, $df = 152$, $p = 0.064$), and to 2017(paired $t = -1.075$, $df = 58$, $p < 0143$) and (paired $t = 1.780$, $df = 152$, $p = 0.039$), respectively.

5. Discussion

The mean value of PM 2.5 in 2020 was drastically decreased especially January 23 to February 20 comparing with previous years. Since the rise-and-fall pattern of the mean PM 2.5 synchronizes with the one of wind speed it can be said the decline was caused by the wind speed somewhat. However, it could not explain the amplitude of the decline since the changing pattern of the wind speed in 2020 was not significantly different from previous years. Besides, there were no major government interventions made. Therefore, there must be other reasons such as local activities related to biomass burning at agricultural field, or proactive self-imposed ban initiated by individuals and organizations to prevent infections from COVID-19. On the other hand, the National-level State of Emergency Decree seemed to work on reducing PM 2.5, in other words, to control economic activities. Since causal correlation of wind speed acts on PM 2.5 in opposite way; PM 2.5 decreased towards March 28 while wind speed became slower. Understandably, one meteorological factor is not sufficient to determine the result, decline of the causal correlation was observed between wind speed and mean value of PM 2.5 during one month after the issue of the decree ($t = -4.650$, $SE = 1.108$, $p < 0.001$). There were two peaks observed during April 21 to May 2, and the day of May 11. It can be said that both happened due to the sharp decline of wind speed, PM2.5 did not sweep away but stayed in the area. For the former, additional reason can be considered that during the period, wind direction changed from southern-majored direction to mixed directions from northern and eastern that PM 2.5 from other locations flew into the target area.

Tendency of PM 2.5 change was partially different from the results obtained from previous research conducted by the authors which focused on not PM 2.5 but Nitrogen Dioxide (NO2) [16]. Previous studies identified significant differences in NO2 for the period January 1 to April 30 in 2019 and 2020 (paired $t = 4.908$, $df = 116$, $p < 0.001$), while no significant differences were identified for May 1 to July 23 (paired $t = -0.524$, $df = 78$, $p = 0.602$). To detail the insights obtained from the results, factors which might cause the different behavior of mean PM 2.5 value should be considered. Since Ayutthaya is known as the province that possess number of major industrial estates and parks, and tourism industries these influences towards the change of mean PM 2.5 is discussed.

Rojana IP is one of the biggest industrial sectors in Ayutthaya Province where AI decreased drastically from 2019 to 2020 as shown in Fig. 3. As PM 2.5 is one of the compositions of aerosol being also emitted from industrial areas, the reason of significant decline in 2019 can be assumed to be a decline of activity level in the park. The park's consolidated revenue of total sum of service and rental sections in first quarter in 2020 was 190,967 Thousand Baht, and it was increased at the same quarter of 2019 of 180,061 Thousand Baht (6.06%). The detailed revenues source includes water sales for industrial use, service of wastewater treatment, and public service fees from water consumption for the industrial use. In contrast to the first quoter, the revenue dropped significantly at 29.21% from 235,394 Thousand Baht to 166,630 Thousand Baht, from second quarter of 2019 to 2020. Eventually, the revenue in entire 2020 resulted in 14.00 % decline from 2019. Rojana Industrial Park Public Company Limited clarified the reason in its report of consolidated statement was because of the COVID-19, particularly due to reduction of working hours of factories related with the park [17]. This situation synchronizes with the PM 2.5 changes that higher value until March (first quarter) and dropped and continued since (second quarter). Therefore, it can be said that the reason of continued low value of mean PM 2.5 from March can be explained due to the lower activities of companies and factories of Rojana industrial Park, which are different from activities of public lives. For further understanding of industrial activity, electricity consumption can be considered. Electricity consumption decreased at 11,102.22 million units in 2020, which is 6.36 percent decline from 2019. This is the first time since 2007 that electricity consumption has fallen below average usage [18]; comparing electricity usage by month, 2020 showed 4.66 percent and 1.31 percent increases in January and February, respectively, and 1.82 percent and 3.26 percent decreases in March and April, respectively, compared to 2019. The Provincial Electricity Authority speculates that they attribute this drop in electricity usage is due to a contraction of production lines in automotive and steel factories.

Tourism characteristics of Ayutthaya is summarized as followings based on the interview with TAT. Ayutthaya province currently has five industrial parks/estates including the above mentioned Rojana Industrial Park, and a large number of shuttle buses need to be run through for employees to commute. Since this air pollutant materials emotion form the buses affects archaeological site's environment the Fine Arts Department, the Ministry of Culture, has been looking for solutions. According to the policy of restricting people and distancing themselves in recent times, fewer tours and cars have been set up and designated parking spots that mitigate the impact on archaeological sites. Mean PM 2.5 decline in 2020 does not seem to occur due to the traffic control for environmental protection by the government since the policy is still not strong enough to realize the huge impact to reduce air pollutant emission including PM 2.5. Other than the policy reduction of number of tourists would have higher impact.

For Thai travelers to Ayutthaya, the target is on some specific interests such as the routes of sacred places and other places of worship, such as Sakae Temple, Tako Temple, etc. Also, they are likely to go to restaurants and cafés which provide photo corners or celebrity's reviews. A popular place needs to be booked before visiting and using their services. One of the weak points was that the tourists were only crowded during the weekend. On weekdays, students often go with school excursions, but during the COVID-19 pandemic, this group of tourists was reduced due to the government and related agencies' policies. The overall situation was getting better since August 2020 until the end of 2020 due to Loy Krathong festival and the World Heritage Sites Festival. However, in January 2021, the number of tourists dropped significantly. The operating rate dropped to below 10% due to the new outbreak and began to improve again but still not as same as December 2020 (30-40% of the operating rate). Many hotel businesses who paid attention to Chinese and foreign tourists have adapted their plan to attract the domestic tourists. For small to medium-sized hotels, they started to give the online vouchers with special promotions to the tourists. As a result, it became a turning point to pay more attention to Thai tourists which is a potential way at this moment.

Based on the interview data with the Director of the Tourism Authority of Thailand in Ayutthaya, there is possible effect due to the government's regulation as well. The Ministry of Tourism and Sports, Ministry of Education, and Ministry of Public Health are the main organization issued the related regulations [19]. Interesting outcomes of the results was that the data, mean PM 2.5 change, can give us meaningful insights that government interventions does not elicit its effect immediately for controlling economic activities in Ayutthaya, but the effects are produced in different timing and contexts. That would result in that the province where has major industrial estates/parks and attracts a large number of tourists, shows different patterns of relationship between mean PM 2.5 and government interventions compared to other cities in Thailand.

6. Conclusion

Various measures were taken by the Thai central and local governments, various industries, and even individuals to prevent the spread of the Coronavirus disease (COVID-19), an unprecedented pandemic. While it is obvious that socioeconomic activities have been significantly affected by these interventions and measures, the details of their impacts on the changes in socioeconomic activities are yet to be determined. Thus, this study analyzed the factors that influence socioeconomic activity conditions in the COVID-19 by comparing changes in atmospheric composition with socioeconomic activity trend over time and space using Google Earth Engine and Earth observation data by taking meteorological and hydrological factors. PM2.5, one of aerosol composition, and Phra Nakhon Si Ayutthaya Province were chosen for the case study. The spatiotemporal analysis and the study of industrial complex and tourism yielded the following results;

- The value of Aerosol Index in 2020 in urban areas of the province decreased by 28.03% compared to 2019, with the most significant changes in the Rojana Industrial Park and parts of the town area.
- Wind speed has the highest cauasal relationship with mean PM 2.5. Mean PM 2.5 drastcally decreased from March 2020 and kept low level compared with previous years.
- Other than governemnt interventions, especially National-level state of the emergency decree, reduction of factories' actitvities at Rojana Industrial Parck and reduction of the number of tourists had significant influence to reduce mean PM 2.5.

For further study, it is recommended to compare other areas of urban-rural distribution with similar and different industrial, commercial, agricultural, residential, and tourism using the same methodology for deeper and more detailed insights of influential factors on a change of each atmospheric composition. Besides, for further analysis, it is recommended to utilize supplementary multifaceted data sets, such as human flow data and data on the usage of critical infrastructure, in addition to earth observation data. In addition to strict governmental interventions and measures such as emergency decree and curfews, the popularization of crisis awareness and safety measures by individuals may also have an impact on socioeconomic activities. Since sentiment analysis of mobile data such as Twitter also contributes to the analysis of those human behaviors and sentiments [20], it will be effective in furthering the results of this study.

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