GEO-INFORMATICS PLATFORM FOR THE SPATIAL HOLISTIC MANAGEMENT OF THE PM2.5 IN THAILAND

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ABSTRACT: High level of PM2.5 concentration is known to not only affects human health and quality of life but also hinder economic and social development. The systematic management and solution to control PM2.5 requires accurate spatial information and up-to-date spatio-temporal data. This study aimed to study, collect and analyze satellite imagery, geospatial data, ground-based measurements and other PM2.5-related physical factors which were then utilized to assess near-real time concentrations of surface-level PM2.5 at hourly basis over Thailand. The satellite-based measurement from Moderate Resolution Imaging Spectroradiometer (MODIS) and Himawari-8 was used. MODIS data was analyzed to understand long-term spatio-temporal pattern of PM2.5 concnetration over the country. Data derived from Himawari-8 was integrated with ground-based measurement and physical modeling using wind speed, air pressure, relative humidity, vegetation indices, and topographic data to allow for gap-filling where there is missing data. Moderate agreement was found between the in-situ measurements of PM2.5 and instantaneous estimates made from the satellite data with R^2 of 0.5-0.6. High concentration of PM2.5 over 19 $\mu g.m^{-3}$ was found at central and northern region of Thailand, while the increasing trend of ~1 $\mu g.m^{-3}$ from 2002 to 2021 was identified near the north and north easter boarder. Open geo-spatial platform for PM2.5 management was successfully developed based on Himawari-8 in combination with multi-source ground and satellite-based physical data. This platform provides consistent, up-to-date, and reliable PM2.5 concentration in continuous grid data which can be supported planning to response and alleviate the negative impact from PM2.5.

1. INTRODUCTION

PM2.5 is fine particulate matter in which its diameter measure with 2.5 micrometer or smaller. PM2.5 is one of air pollutant that causes global concern as it threatens both short and long-term health of human and the environment (World Health Organization, 2013). The challenges in monitoring and identifying the source of PM2.5 leads to ineffective prevention and control measures. Near-real time spatio-temporal information of PM2.5 is fundamental for both the public and government to appropriate response to PM2.5 issues. Thailand similarly faces increasing PM2.5 level in many parts of the country. The monitoring of Thailand PM2.5 has relied heavily on ground-based monitoring station. Since measurements from ground sensors are limited to where the instrument is installed, large network of instruments is required. However, limited human and monetary resources along with logistical difficulty prevent such implementation.

Satellite-based measurement can be used to regularly monitor PM2.5 which help to bridge the gap of ground-based instruments. Not only PM2.5 that can be measured from satellite, various types of products from environmental satellite exist to measure different characteristics of the earth. The integration of multi-sourced PM2.5 spatial data from both ground-based and satellite-based, as well as other relevant environmental parameters, can enhance knowledge of PM2.5 at a macro-level. To support decision-makers and citizen alike, near-real time spatial-temporal PM2.5 information must be easily accessible and interpreted.

2. OBJECTIVES

This study aims to implement open-access geo-spatial platform for the dissemination of near-real time hourly surface PM2.5 data for Thailand. To achieve this, the follow objectives must be fulfilled: -

1. To analyze spatio-temporal trend of PM2.5 concentration of Thailand
2. To integrate multi-sourced data to provide hourly near-real time report of surface PM2.5 level and relevant factors
3. To develop geo-spatial platform providing near-real time surface PM2.5 data and relevant factors

3. DATA AND METHODOLOGY

The data used in to implement this geo-spatial platform include PM2.5 data and related environmental data which were obtained from both satellite-based measurement and ground-based instruments.

3.1 Satellite Data

Moderate Resolution Imaging Spectroradiometer (MODIS): MODIS provide global daily measurement of aerosol optical thickness (AOT) which can be processed to PM2.5 at the surface level. The sensor has a large scan angle with a field of view of ± 55º off-nadir, which yields a spatial coverage of 2,330 × 2,330 km2. MODIS is a whiskbroom scanning imaging which obtains a 12-bit high radiometric resolution (Jensen, J.R, 2007). The satellite passes over Thailand at approximately 11:30 AM local solar time. The Level-2 product, namely the MODIS Aerosol Product at 3 km resolution within the latest Collection 6.1 (MOD04_3K) for 2002 to 2021 was acquired from the National Aeronautics and Space Administration Land Processes Distributed Active Archive Center. A total of 20,590 images were used. The data was in Hierarchical Data Format - Earth Observing System (HDF-EOS) format, which contained 25 object files including Aerosol_Type_Land that were used in this study.

Himawari-8: Himawari-8, launched in 2014, is a geostationary satellite with its spatial coverage over part of the west Pacific Ocean and the east of Asian continent. The Advanced Himawari Imager (AHI) onboard Himawari-8 provide high temporal information with its Full Disk image available every 10-minute. Its main mission is for weather and environmental monitoring using 16 different bands of wavelengths including visible and infrared spectrum. Himawari-8 provides level-2 and level-3 AOT products in Network Common Data Form (NetCDF) as shown in Table1. The Level-2 product used Angstrom Exponent (AE) and Angstrom turbidity coefficient to obtain AOT at 500nm wavelength. The Level-3 product can be divided based on its temporal resolution. In this study, The L3APR Hourly product was used. It enhances the accuracy of Level-2 product through cloud masking resulted in AOT_Pure and AE_Pure data. In additional, spatiotemporal variability technique was applied on AOT_Pure and AE_Pure to obtain AOT_Merged and AE_Merged. This L3APR Hourly product provide hourly data since 2020 to present with spatial resolution at 0.05 x 0.05 degree (JAXA Earth Observation Research Center,2020), (Japan Meteorological Agency, 2018).

Table1. Aerosol products available from Himawari-8

Product	Parameter	Spatial Resolution	Temporal Resolution	Processing Time
L2ARP	*AOT at 500 nm **AE	0.05 degree	10 minutes	40 minutes
L3APR Hourly	Mean L2 AOT, AE L2 AOT, AE with strict cloud screening (AOT_Pure, AE_Pure) Spatiotemporal interpolation of AOT_pure and AOT_Pure within 1 h (AOT_Merged, AOT_Merged)	0.05 degree	1 hour	1 hour
L3APR Daily	Mean L2, L3 AOT and AE	0.05 degree	1 day	1 day
L3APR Monthly	Mean L2, L3 AOT, AE	0.05 degree	1 month	1 month

*AOT = Aerosol Optical Thickness or Aerosol Optical Depth (AOD),
**AE = Angstorm Exponent

3.2 Ground Data

Air quality monitoring station: Thailand Pollution Control Department (PCD) established a ground network of air quality-monitoring stations. These stations comprised of various sensors that measure diverse pollutants, including PM2.5, PM10, Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Ozone (O3), Sulfur Dioxide (SO2), as well as meteorological factors, such as wind speed and wind direction, air temperature, relative humidity, air pressures, and rain. The monitoring of PM2.5 from these ground measurement stations has started since 2018 and complied with the standards of the United States Environmental Protection Agency (U.S. EPA). In 2021, the data from 65 official air quality-monitoring stations (Figure 1) can be accessed real-time via website, www.air4thai.pcd.go.th. (Pollution Control Department, 2022)

Automatic weather station: Thailand Meteorological Department (TMD) installed and managed 128 automatic weather stations around the country (Figure 1). These stations provide 3-hour meteorological data which can be access via web service, https://data.tmd.go.th/api/Weather3Hours/V2/?uid=api&ukey=api12345. The meteorological data available from the stations include wind direction and speed, air temperature, air pressure, relative humidity, and precipitation. Besides the automatic weather stations, TMD also installed other types of monitoring stations around the country. For example, 122 surface air temperature stations, 20 weather radar stations, and 820 automatic rain gauges (Thailand Meteorological Department, n.d.).

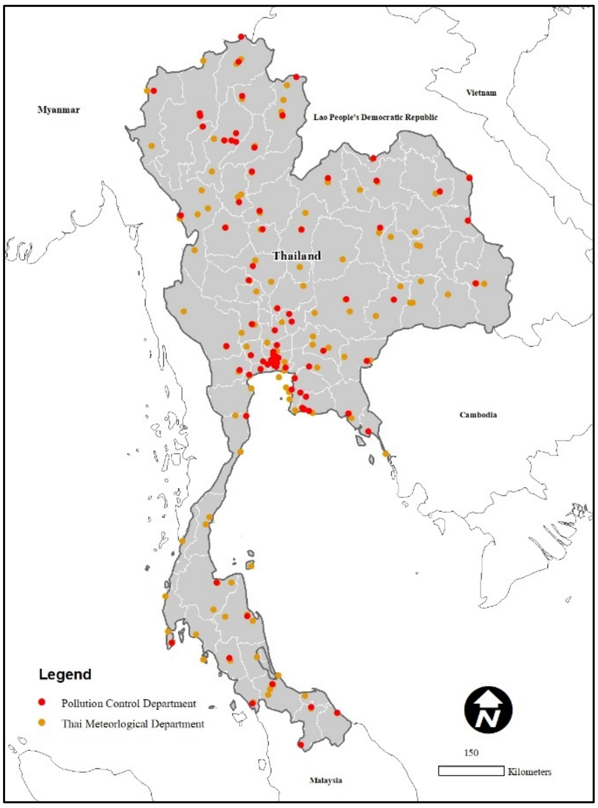

Figure 1. Air quality monitoring station managed by Thailand Pollution Control Department (red) and automatic weather station managed by Thailand Meteorological Department (orange)

3.3 Methodology

To implement the open-geospatial platform which disseminate surface PM2.5 data and other relevant information, this study executed 2 main steps: 1) processing of satellite-based PM2.5 data, 2) generating geo-spatial databases containing satellite-based and ground-based PM2.5 and other related environmental parameters, and 3) developing geo-spatial platform for PM2.5 management.

Processing of satellite based PM2.5 data: This study utilized aerosol products from MODIS and AHI to obtain PM2.5 concentration. Harmonized format that allows co-analysis from both sensors is needed. The general steps to achieve harmonized format for further analysis include converting the data into GeoTIFF format, reprojecting the image into World Geodetic System 1984 (WGS84) geographic coordinate system, and apply radiometric correction using image rectification and resampling method. The specific processing for MODIS and AHI products were describe in the following section.

The MOD4 product in HDF format was used. The processing steps was summarized in Figure 2. The file was processed using ArcGIS software. The sub dataset selection was applied to select Aerosol_Type_Land layer which was then converted into GeoTIFF raster format and reprojected into WGS1984. The raster data was then multiplied with scale factor of 0.00100000004749745. Multiple regression in (1) was applied to infer PM2.5 concentration level from the obtained AOD from MODIS (Richards, J. A., Jia X., 2006), (Gupta, P. et.al, 2006).

$$PM2.5 = (29.4 \times AOD_{MODIS}) + 8.8 \quad (1)$$

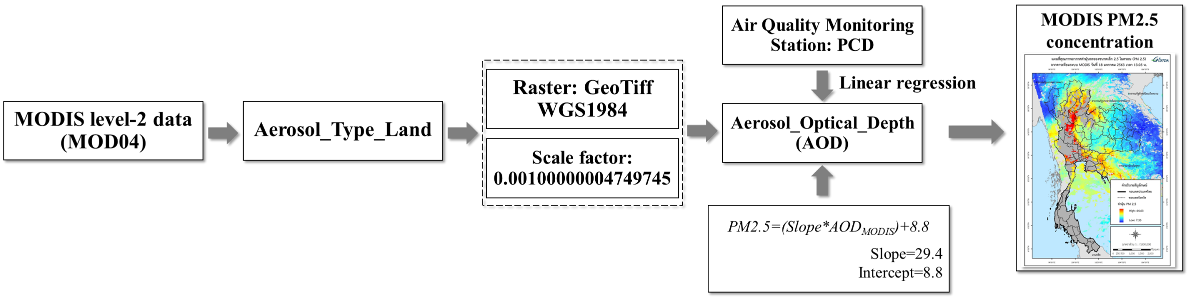

Figure 2 Processing steps to obtain PM2.5 concentration from MODIS

The Level-3 Himawari-8 AHI AOD product at hourly level (L3APR Hourly) was used. The processing steps was summarized in Figure 3. The data file was in netCDF format with multiple layers of data which was converted. Using ArcGIS software, the file was converted into raster file in GeoTIFF format and projected into WGS1984. The AOT_Merged variable layer as grid value, X Dimension as longitude, and Y Dimension and latitude. The obtained raster was then multiplied with scale factor of 0.0002. To infer AHI-based AOD product to PM2.5 concentration, this study compared the AOD data with ground-based measurement of PM2.5 based on 3 seasonal periods to generate relevant regression model. The rainy season starts from the middle of May to the middle of October. The winter season starts from the middle of October to the middle of February. Lastly, the summer season starts from the middle of February to the middle of May. The PM2.5 concentration can then be obtained from AOD for winter, summer, and rainy season using (2), (3), and (4) regression, respectively.

$$PM2.5(winter) = 18.199 + 69.885(AOD) + 7.433(AOD)^2 - 23.330(AOD)^3 \quad (2)$$

$$PM2.5(summer) = 27.994 + 25.270(AOD) + 27.7(AOD)^2 - 12.128(AOD)^3 \quad (3)$$

$$PM2.5(rainy) = 14.741 + 80.193(AOD) + 148.710(AOD)^2 - 98.193(AOD)^3 \quad (4)$$

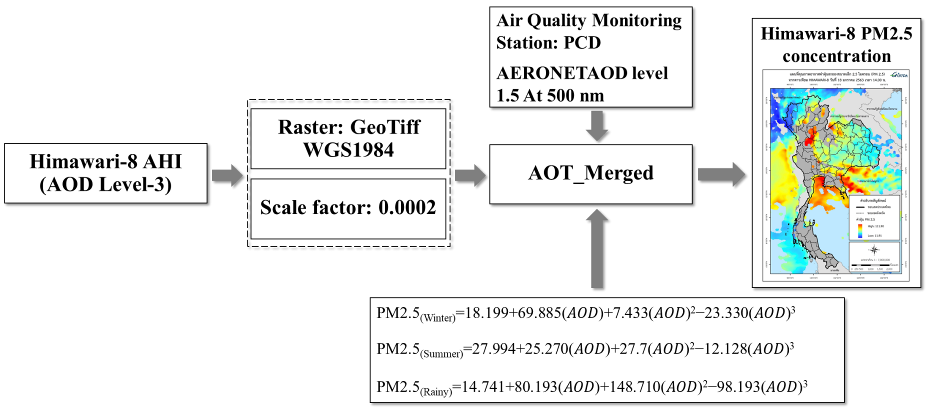

Figure 3 Processing steps to obtain PM2.5 concentration from AHI onboard Himawari-8

Generating PM2.5 geo-spatial data with multi-sourced data integration: To support effective and efficient analysis of spatio-temporal distribution of PM2.5 concentration, it is necessary to obtain continuous grid data. In this study, integration of multi-sourced data was used to infer any missing PM2.5 observation which was primarily based on Himawari-8 observation.

The AOT product from Himawari-8 was used as a base data to provide spatial hourly PM2.5 concentration level. Factors related to the source of PM2.5 obtained from both satellite-based and ground-based measurement were used in combination to identify any missing observation. The major sources are based on existing knowledge are believed to be urbanized area and agriculture area. Various data can be used to identify or classify surface types. For example, vegetation indices such as Normalized Difference Vegetation Index (NDVI), and grid-based population. Meteorological data can also affect level of PM2.5 concentration. Unlike more static surface characteristics, weather is highly variable due to regional climate influences. Hence, this study developed a dynamic model to infer PM2.5 concentration from multi-sourced data. The multiple regression was created with dynamic coefficient. The detail of the model was described in the following steps (Figure 4).

Hourly AOT from Himawari-8 that corresponded to the location of PCD air quality stations was obtained. The 3-hour meteorological data including air temperature, wind speed, relative humidity, air pressure from 128 automatic weather station was then obtained via TMD web services. To infer land surface types, the weekly 3-year averaged NDVI from Suomi-NPP was used. The geographical data from Shuttle Radar Topography Mission (SRTM) was also obtained and used when interpolating ground-based meteorological parameters. All data were resampled to the same resolution with Himawari-8 spatial resolution. After all independent variables were obtained, multiple linear regression was applied with all aforementioned data to train using 65 ground based PM2.5 data from PCD air quality stations. Three equation was obtained, namely $PM2.5_{himawari}$ (5), $PM2.5_{land}$ (6), and $PM2.5_{atmospheric}$ (7). Land and atmospheric equations were generated to compensate when Himawari equation cannot be used in case any issues occur with Himawari-8 satellite. Atmospheric equation is used over water surface where NDVI data is not available.

$$PM2.5_{himawari} = a_0 + a_1 \cdot HMW + a_2 \cdot NDVI + a_3 \cdot DEM + a_4 \cdot PRES + a_5 \cdot WP + a_6 \cdot RHUM \quad (5)$$

$$PM2.5_{land} = b_0 + b_1 \cdot NDVI + b_2 \cdot DEM + b_3 \cdot PRES + b_4 \cdot WP + b_5 \cdot RHUM \quad (6)$$

$$PM2.5_{atmospheric} = c_0 + c_1 \cdot PRES + c_2 \cdot WP + c_3 \cdot RHUM \quad (7)$$

PRESS, WP, and RHUM are the air pressure, wind speed, and relative humidity as measured at the TMD automatic weather station. HMW refers to hourly AOT data from Himawari-8.

The coefficient a_i, b_i, and c_i are generated and stored in the database which can be later retrieved. The best multiple regression equation was identified using least square adjustment (8).

$$v + B\Delta = f \quad (8)$$

In this equation, v represents residual matrix. B refers to coefficient matrix. Δ is the variable matrix needed solution. f is the matrix of the observation values.

The performance of equation (6), (7), and (8) is evaluated by calculating R^2 and correlation coefficient. All parameters and equations were stored and updated hourly. Every hour, Himawari model based on equation (2) – (4) will be supplied to equation (5). In the case with missing Himawari-8 data, Land model and Atmospheric model which better performance will be used. The output file is in continuous grid data which was then used as a basis to calculate province, district, and sub-district averaged using zonal statistics. This analysis result is reported via web map and online dashboard.

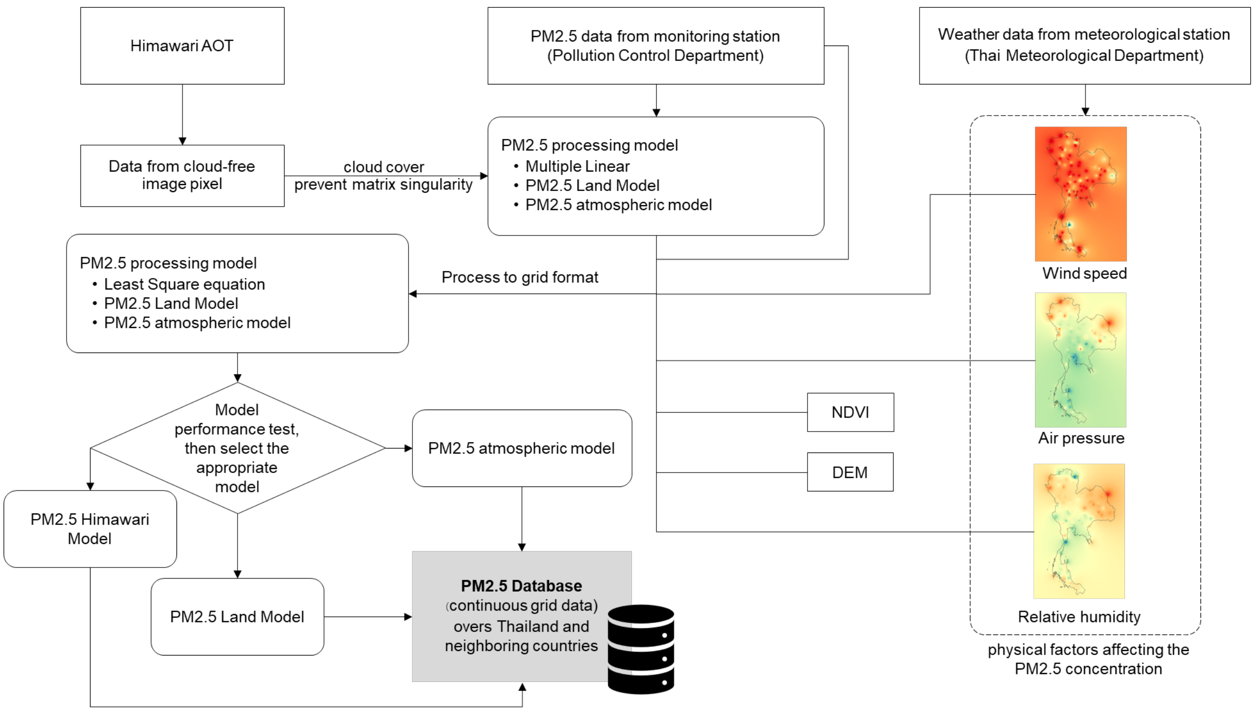

Figure 4. Concept map for processing PM2.5 data from satellites with ground station and related physical factors affecting automatic PM2.5 concentrations

Developing geo-spatial platform for PM2.5 management: The geospatial platform to disseminate PM2.5 data was implemented via both web and mobile application which aim to support PM2.5 manage in all level from individual to government level. The geospatial database was developed and display via geospatial portal linked using Web Map Context (WMC) service. This is in compliance to National Geographical Infrastructure System (NGIS). The conceptual from in developing geo-spatial platform for PM2.5 management is shown in Figure 5.

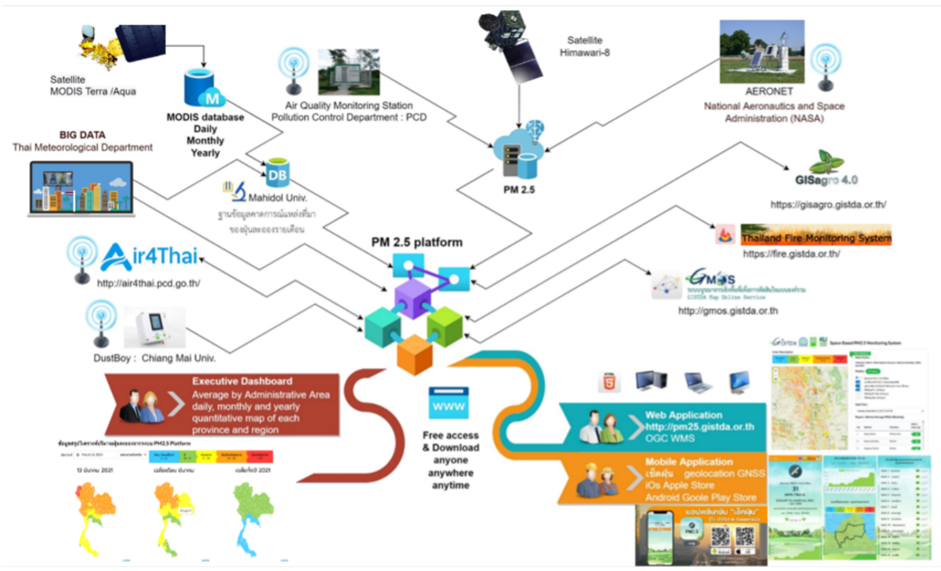

Figure 5. Conceptual framework of the geo-spatial platform for PM2.5 management

4. RESTULS AND DISCUSSION

4.1 Comparison of Satellite- based PM2.5 Concentration and Air Quality Monitoring Stations

Comparison of PM2.5 concentration derived from MODIS and Himawari-8 to ground-based measurement showed moderate similarity. Figure 6 shows average R^2 of 0.51 between MODIS-derived PM2.5 concentration at 3 x 3 km^2

and that from ground-based station. Figure 7 similarly shows PM2.5 concentration from Himawari-8 at 6 x 6 km^2 and ground-based station with an average R^2 of 0.55.

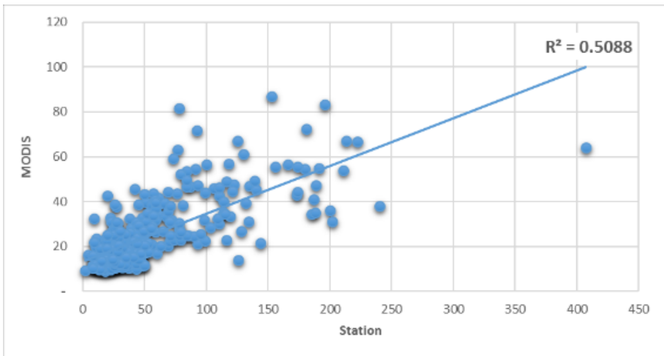

Figure 6. Scatter plot of PM2.5 concentration from MODIS ($\mu g.m^{-3}$) and the ground station during 2019-2021 (n=324)

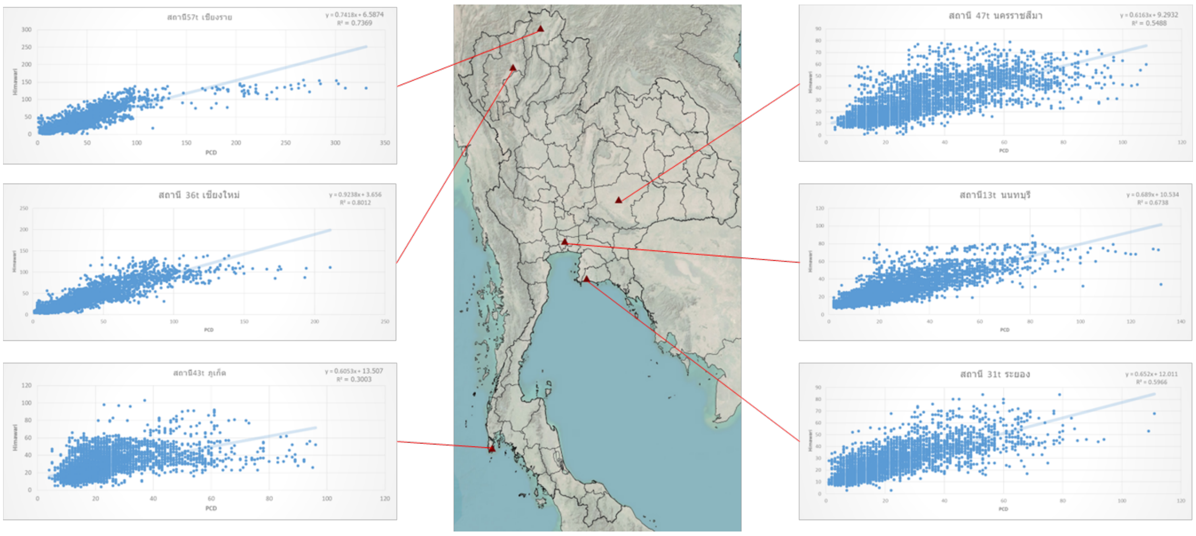

Figure 7. Scatter plot of PM2.5 concentration from Himawari-8 ($\mu g.m^{-3}$) and the ground station

An important uncertainty associated with co-location of satellite and ground measurements are spatial and temporal sampling errors which may result in moderate R^2. The PM2.5 concentration derived from satellites are area-based measurement, while ground-based station is a point measurement. MODIS provides measurement at 3 x 3 km2, while Himawari-8 provides even coarser 6 x 6 km2 spatial resolution. Additionally, multiple measurements within an hour can be obtained from ground-based station, but satellite measure the ground in mill-second. Therefore, it is difficult to obtain perfect agreement between satellite-based and ground-based measurement.

4.2 Long-term Trend of Thailand PM2.5 Concentration

To understand the spatial and temporal pattern of PM2.5 concentration over Thailand, MODIS-derived data from 2002 to 2021 was used. Figure 8 shows high concentration of PM2.5 in central region (19.91 $\mu g.m^{-3}$) and northern region (19.11 $\mu g.m^{-3}$). Other region had lower PM2.5 concentration with 18.92, 18.75, and 16.16 $\mu g.m^{-3}$for northeastern, eastern, and southern region respectively. The highest level of PM2.5 concentration was found during dry or summer season during March and April (Figure 9). Specifically looking at the dry season, we found that northern and northeastern region especially at the border showed an increasing trend of PM2.5 concentration from 2002 to 2021 with approximately 1 $\mu g.m^{-3}$ increased per year.

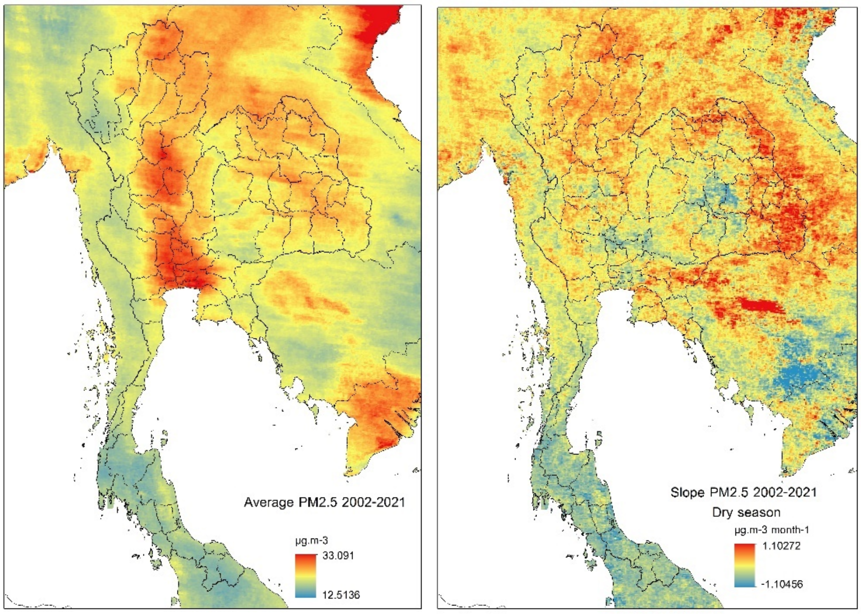

Figure 8. Average PM2.5 concentration from 2002 to 2021 (left) and trend of PM2.5 concentration during dry season (right) from 2002 to 2021

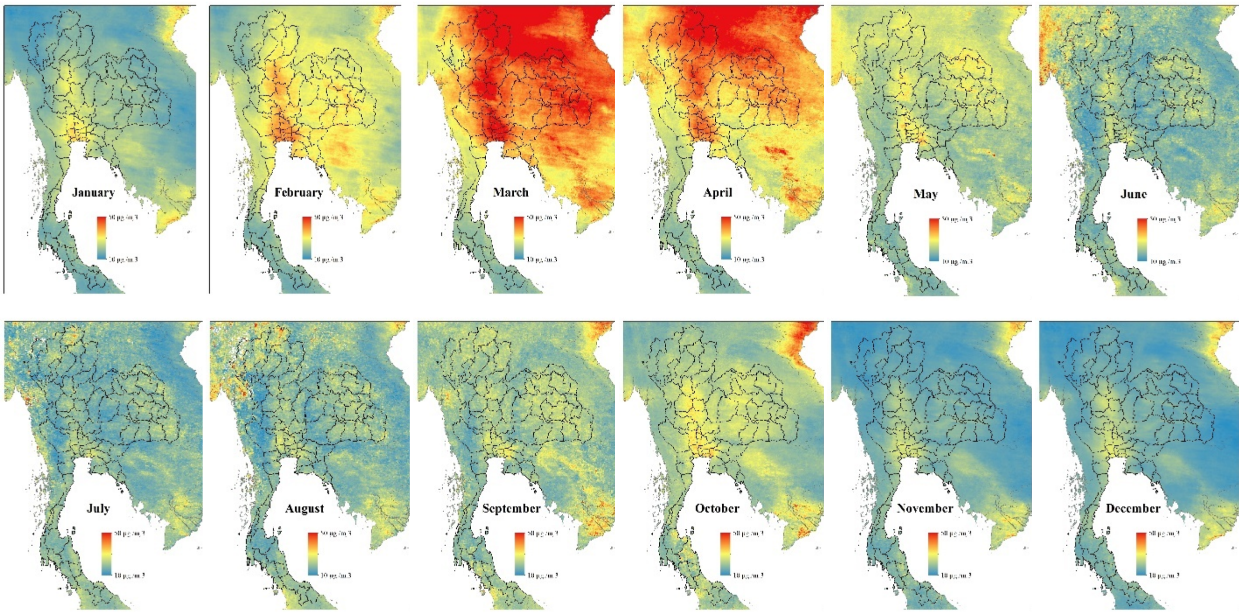

Figure 9. Average monthly PM2.5 concentration from 2002 to 2021

4.2 Geo-spatial Platform for PM2.5 Management

The product from Himawari-8 provides 6 x 6 km^2 spatial resolution every hour which is adequate to monitor PM2.5 situation over Thailand. Its hourly characteristic allows near-real time identification of PM2.5 concentration, its movement, and its potential sources. By integrating Himawari-8 data with ground-based measurement, meteorological parameters, and other physical factors, the geo-spatial platform for PM2.5 management was developed. The platform provide data via both web and mobile application (Figure 10). The users can browse information in their current location and linking to relevant surface activities and other data, such as agriculture planting areas, active fire location. With continuous grid data, near-real time characteristics, and its multi-source data integration, the platform has potential to support time PM2.5 warning and management.

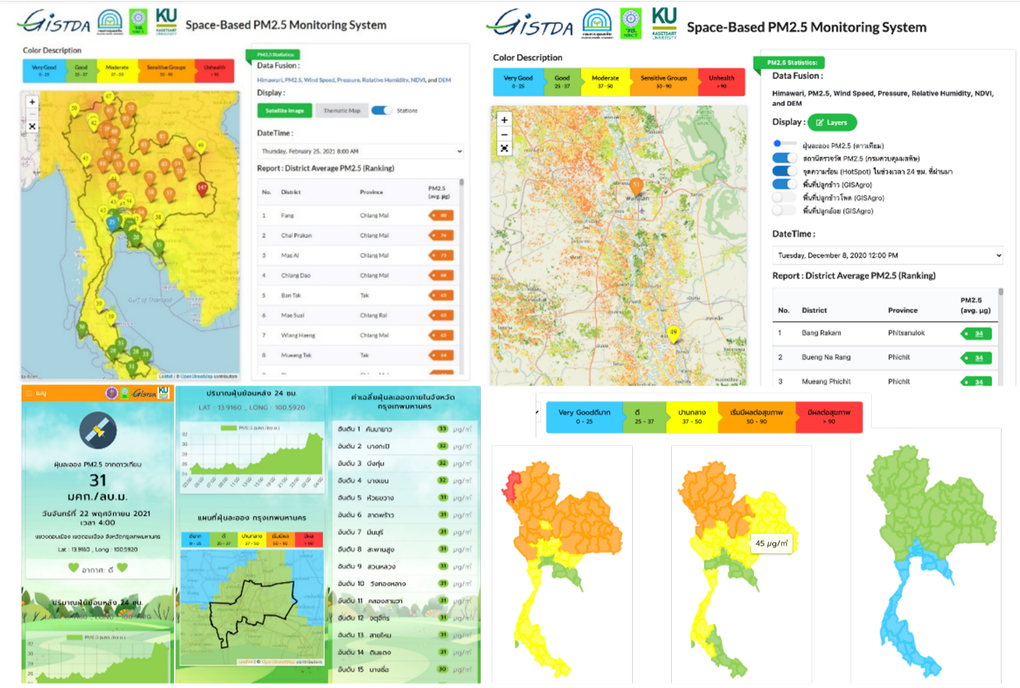

Figure 10 Geo-spatial platform for PM2.5 management

5. CONCLUSION

This study aims to implement open-access geo-spatial platform for the dissemination of near-real time hourly surface PM2.5 data for Thailand. The surface-level PM2.5 concentration developed for this platform was integrated using multi-sourced data from satellite-based and ground-based aerosol measurement, as well as relevant physical parameters. We believed that by allowing wider access to consistent, up-to-date, and reliable geospatial data of PM2.5, relevant sectors and even individuals can have evident-based data to support their decision to response and alleviate the impact from PM2.5.

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