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Forecasting $PM_{2.5}$ Concentrations Using Mathematical Models and Satellite Imagery to Find Guidelines for Setting Standards under the Environmental Law, In an Industrial Area in Samut Prakan Province

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Abstract

This study aims to forecast $PM_{2.5}$ concentrations using mathematical models from satellite imagery of LANDSAT 8 at band 1-7 wavelengths and applied to a correlation analysis using the equation as 11 models with data from the five ground monitoring stations in Samut Prakan Province during October 2019 - April 2020. The results of this study indicated that the suitable equation model was Cubic ($Y= b_0+b_1X+b_2X^2+b_3X^3$) which had the highest R^2 value of 0.959, and the Quadratic ($Y= b_0+b_1X+b_2X^2$) model had the highest R^2 value of 0.98. Besides, it was found that the evaluation of accuracy or RMSE was as low as 0.39 of relationship with surface reflection data, and the lowest RMSE value was 0.90 of the relative optical thickness (AOT) data. Low RMSE value means high accuracy and precision of the $PM_{2.5}$ predictive performance, which can be used to predict $PM_{2.5}$ concentration through $PM_{2.5}$ maps. It was found that during December 2019 and February 2020, there was a small amount of $PM_{2.5}$ accumulated in the Bang Pu and Bang Phli industrial estates, which are industrial areas. Therefore, it could be concluded that satellite imagery could be used to analyze and determine the guidelines to solve the problems and to formulate standards in accordance with the environmental laws of $PM_{2.5}$ emission from industrial areas.

Keywords : satellite imagery of LANDSAT 8; forecasting $PM_{2.5}$ concentrations; industrial area source; environmental laws standard

Introduction

Today, our world is rapidly and increasingly changing in nature and climate. The global average temperature increased by 1.5-2 °C, leading to global warming, the main cause was the emissions of human activities, especially in industrialized areas. When the GDP (Gross Domestic Product) assessment measures the quality of life, society, and economy, encouraging the private sector to invest in the industrial plant is a portion of its economic development. Last year, $PM_{2.5}$ covered and spread in many areas, making the occurrence of SMOG. Causing an impact on the quality of life, increased health costs, emissions of $PM_{2.5}$ into the environment must comply with various regulations under established legal provisions. Therefore, it is imperative to develop a domestic environmental quality management system.

A mathematical model was used to predict $PM_{2.5}$ by taking the picture from satellite LANDSAT 8. Landsat 8 is an American Earth observation satellite launched. It used to explore the natural resources of the United States. It was applied to analyze the relationship with $PM_{2.5}$ microscopic particulate matter measured at the PCD's ground monitoring station in Samut Prakan industrial areas, which have more than 6,758 industrial plants, two industrial estates, which are the major sources of air pollution **(Figure 1).**

The results of predicting $PM_{2.5}$ concentrations can lead to dust mapping and finding solutions for problem management and setting standards under the environmental laws of $PM_{2.5}$ emissions from industrial areas. The study found that used LANDSAT 8 satellite imagery to map the PM_{10} dust concentration by looking at the correlation with the data from the air quality monitoring station by regression equation. It was found that the optical thickness data (AOT: Aerosol Optical Thickness) with the quadratic equation was accurate [1]. Geospatial Engineering and Innovation Center) (KGEO), the Institute of Field Robotics under King Mongkut's University of Technology Thonburi (2006) [2] reported the utilization of the $PM_{2.5}$ maps for central and local air quality management planning. Lili, Z. and el al. (2020) [3] estimated the $PM_{2.5}$ concentrations using remote sensing. The data showed similar distribution trends to those observed. Assessment of $PM_{2.5}$ concentrations using AOD data found that the surface's relationship increases significantly [4]. Tongwen L. and et al. (2017) [5] estimate ground-level $PM_{2.5}$ from satellite images and measurement stations that they have better spatial relationships than neural networks.

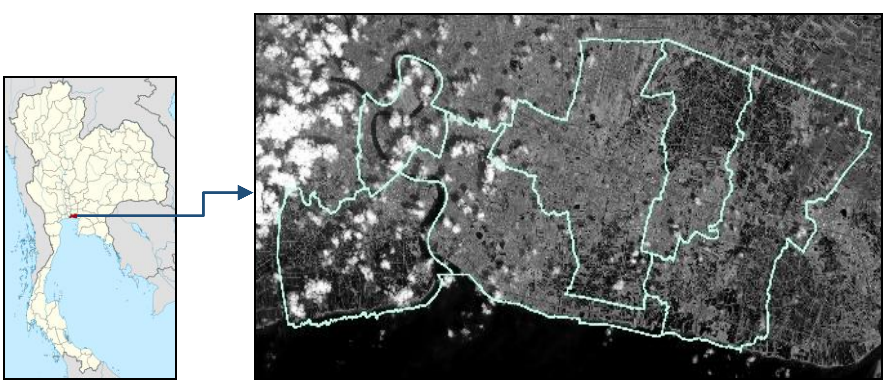


Figure 1 The study area of Samut Prakan

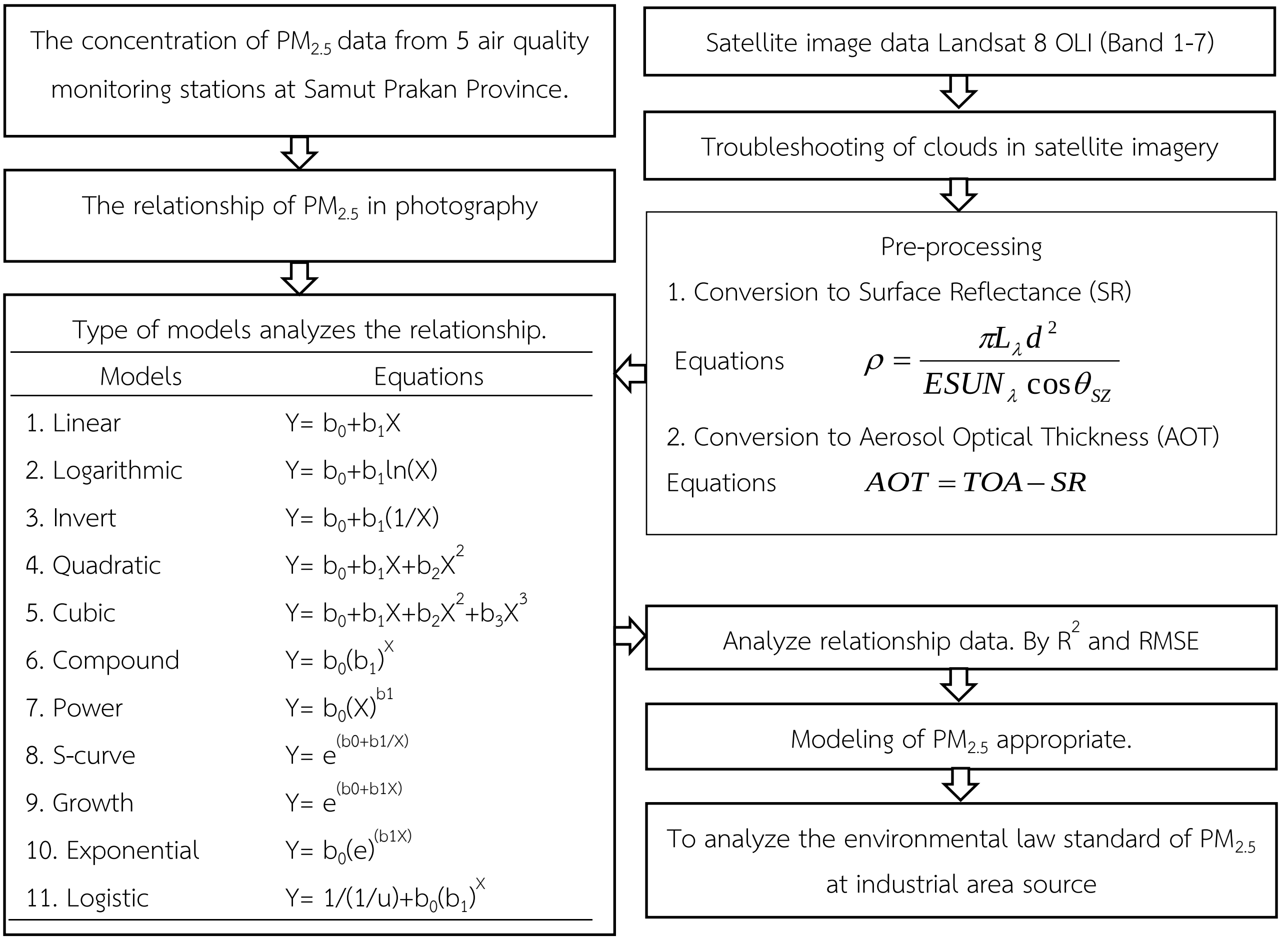


Figure 2 Research methodology

Material and Methods

Figure 2 shows the research operation process. Beginning with the collection of Landsat 8 satellite imagery using only shortwave ranges 1-7 and small dust volumes from the ground monitoring stations of 5 stations, namely, the Disabled and Disabled Vocational Rehabilitation Center (08T), South Bangkok Power Plant (16T), Department of Primary Industries and Mines (17T), City Hall (18T) and Bang Phli Community Housing (19T) from the Pollution Control Department of Thailand.

The results of this study indicated that $PM_{2.5}$ concentration was higher during the winter-summer transition when the atmosphere was near the end of winter with high pressure covering the area, causing a temperature inversion in the lower part area. The atmosphere results in a low level of dust floating and dispersion, improper airflow and ventilation, leading to a build-up of dust.

Therefore, the study period is set from October 2019 - April 2020 and use the information to find the time relationship and positional relationship by using the Geographic

Information Program ArcMap 10.5 to obtain surface reflectance and optical thickness (AOT) by the following equations [6].

1. Conversion to Surface Reflectance (SR)

$$\rho = \frac{\pi L_\lambda d^2}{ESUN_\lambda \cos\theta_{SZ}}$$

Where:

ρ = Surface Reflectance

L_λ = TOA spectral radiance, $L_\lambda = M_L Q_{cal} + A_L$,

where; M_L = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_ BAND _n from the metadata)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

A_L = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata)

d^2 = Earth-sun distance

$ESUN_\lambda$ = Mean solar exo-atmosphric irradiances

θ_{SZ} = Local solar zenith angle, $\theta_{SZ} = 90^\circ - \theta_{SE}$,

where; θ_{SE} = Local sun elevation angle. Provided the scene center sun elevation angle in degrees was provided in the metadata (SUN ELEVATION)

2. Conversion to Aerosol Optical Thickness (AOT)

$$AOT = TOA - SR$$

Where:

AOT = Aerosol Optical Thickness

TOA = Top of Atmospheric, $\rho_\lambda = \frac{\rho_{\lambda'}}{\cos\theta_{SZ}}$,

where; ρ_λ = TOA Planetary Reflectance

$\rho_{\lambda'}$ = TOA Planetary Spectral Reflectance, without correction for solar angle,

$\rho_{\lambda'} = M_\rho Q_{cal} + A_\rho$, where;

M_ρ = Reflectance multiplicative scaling factor for the band (REFLECTANCEW_MULT_ BAND_n from the metadata)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

A_ρ = Reflectance additive scaling factor for the band (REFLECTANCE_ ADD_BAND_N from the metadata)

SR = Surface Reflectance

Data were obtained for quantitative correlation with 11 regression equations using SPSS program to find suitable equation model by considering the coefficient of determination (R^2) and evaluation of accuracy (RMSE). The $PM_{2.5}$ concentration prediction equation was applied to analyze the $PM_{2.5}$ emission source of original area of from clusters of industrial areas and established guidelines for setting standards in accordance with the environmental laws of the industrial areas in Samut Prakan Province.

Results and Discussions

The Pollution Control Department sets the air quality standard for $PM_{2.5}$, the 24-hour mean concentration not more than 50 $\mu g/m^3$, and the 1-year engagement not more than 25 $\mu g/m^3$. The results from the study of the concentration of small particulate matter $PM_{2.5}$ from the ground air quality monitoring station of the Pollution Control Department in the Samut Prakan area, a total of 5 stations are shown in **Table 1.**

Table 1 The amount of $PM_{2.5}$ from the air quality monitoring stations of the Pollution Control Department

Stations	Geographic coordinate		The concentration of $PM_{2.5}$ data from air quality monitoring stations ($\mu g/m^3$)						
	Latitude	Longitude	30/10/19	15/11/19	17/12/19	18/01/20	19/02/20	22/03/20	23/04/20
08T	13.664087	100.543436	31	31	42	64	54	19	20
16T	13.618000	100.556200	21	23	38	46	49	12	15
17T	13.652141	100.531805	21	21	28	49	42	16	17
18T	13.599149	100.597345	42	39	49	63	64	27	31
19T	13.570500	100.786287	27	26	26	46	34	15	19

The results from satellite imagery during October 2019-April 2020 could be used to compare all 5 stations. The findings revealed the highest concentration of $PM_{2.5}$ in January 2020 at the Disabled and Disabled Vocational Rehabilitation Center (08T) and the City Hall (18T), the $PM_{2.5}$ concentration levels were 64 and 63 $\mu g/m^3$, which were higher than the standard criteria. Moreover, in February 2020, at (08T) and (18T), the concentration levels were 54 and 64 $\mu g/m^3$ which also largely exceeded the standard criteria stipulated by law, adversely affecting the climate condition.

From the analysis of correlation, surface reflection data and AOT at wavelengths from band 1 - band 7 during October 2019 - April 2020 using a total of 11 regression equations as shown in **Figure 3**, the results of the analysis of the correlation between $PM_{2.5}$ with surface reflection data, the most suitable equation model is Cubic ($Y= b_0+b_1X+ b_2X^2+b_3X^3$), which has the greatest R^2 value of 0.959 and the Quadratic model ($Y=b_0+b_1X+b_2X^2$) with the highest R^2 value of 0.954.

Also found that some form of equation could not be used in the analysis, and **Figure 4** shows the result of the relationship between $PM_{2.5}$ with AOT. The most suitable form is cubic equation with the greatest R^2 value of 0.980 while the quadratic equation yielded the greatest R^2 value of 0.968.

The correlation analysis was used to find suitable equation patterns to analyze the accuracy of the calculated correlation with the actual measured values of the ground monitoring station through the estimation of Root Mean Square Error (RMSE).

Low RMSE value means high accuracy and precision of the $PM_{2.5}$ predictive performance, which can be used to display the evaluation results of accuracy and suitable equation as shown in **Table 2**, select models, find the RMSE value and then create a state of the equation to calculate the number of small particles $PM_{2.5}$.

The results of a suitable equation model for $PM_{2.5}$ prediction from October 2019 to April 2020 in Samut Prakan Province and comparison with the measured values from the ground measurement stations can be represented as $PM_{2.5}$ map shown in **Figure 5.** The highest monthly concentration levels of $PM_{2.5}$ from October 2019 to April 2020 were 68.8, 214, 122, 101.9, 127.93, 90.9, 73.8 $\mu g/m^3$, respectively. In November 2019 and January 2020, there was a cloud cover area. Hence, the results cannot be used for spatial analysis of industrial origin. Furthermore, comparing the calculated values from the appropriate equation form with the measurement points from the ground monitoring station were found to be similar. **Figure 5** exhibits the $PM_{2.5}$ dispersion over the locations of the industrial estate, including Bangpoo Industrial Estate (No.1) and Bang Phli Industrial Estate (No.2) as an industrial area group where many industrial plants are located. The figures from December 2019 and February 2020 show the amount of small dust $PM_{2.5}$ accumulated in such areas, indicating that the density of industrial plants affected the amount of $PM_{2.5}$ accumulated in the air. In October 2019, March 2020, and April 2020 found the amount of $PM_{2.5}$ in the outer area. It may be the result of such a period of time that the strong wind blows from the source of the industrial area.

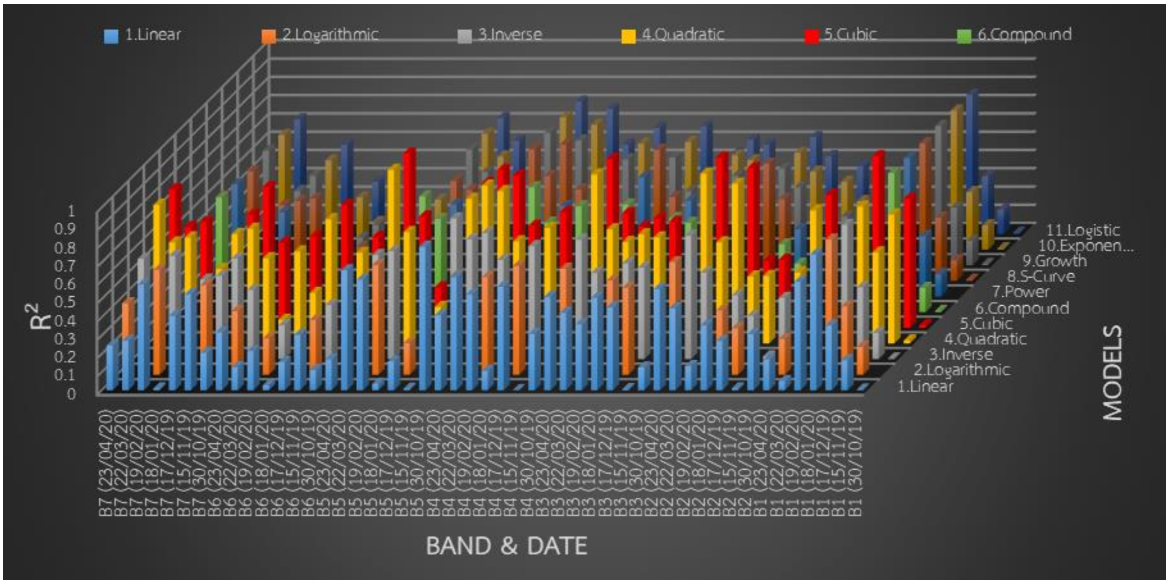


Figure 3 R^2, The relationship of Models with surface reflection data

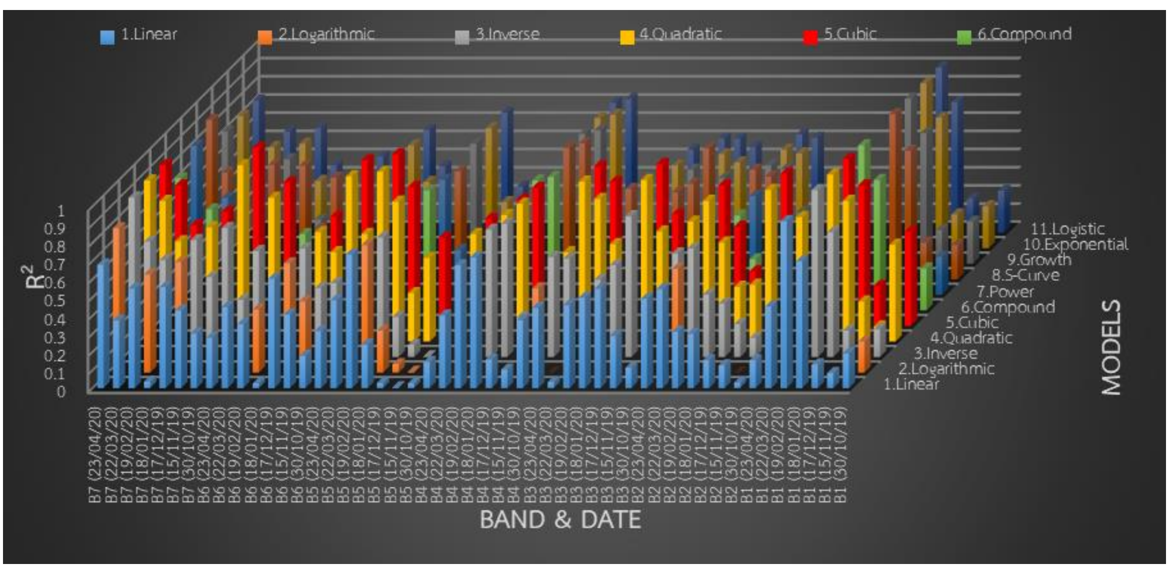


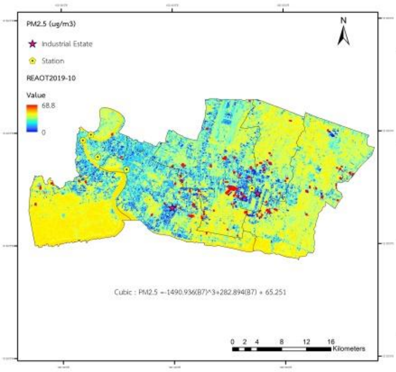
Figure 4 R^2, The relationship of Models with AOT data

Table 2 Shows the results of the RMSE and model of relationship

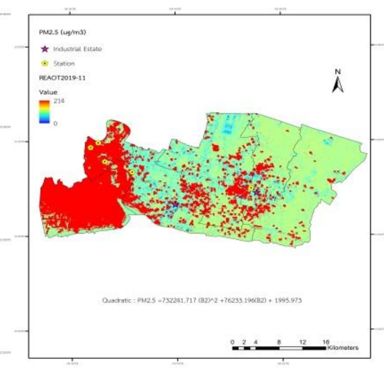
Date	Relationship	Models	RMSE	Equations (n=5)
30/10/2019	Surface Reflectance	Cubic (B5)	2.99974	$PM_{2.5}$ =-1471.027(B5)^3-128.24(B5)^2 + 17.764
	AOT	Cubic (B7)	0.90369	$PM_{2.5}$ =-1490.936(B7)^3+282.894(B7) + 65.251
15/11/2019	Surface Reflectance	Quadratic (B1)	2.09261	$PM_{2.5}$ =59641.922(B1)^2 -21337.695(B1)+1925.97
	AOT	Quadratic (B2)	0.94373	$PM_{2.5}$ =732241.717 (B2)^2 +76233.196(B2) + 1995.973
17/12/2019	Surface Reflectance	Quadratic (B6)	2.39623	$PM_{2.5}$ =-319502.078(B6)^2 +23989.223(B6) -405.103
	AOT	Cubic (B3)	1.78887	$PM_{2.5}$ =4627.69(B3)^3 -1041.49(B3) -10.14
18/01/2020	Surface Reflectance	Cubic (B1)	1.08590	$PM_{2.5}$ =51247.411(B1)^3-22852.201 (B1) + 5916.036
	AOT	Cubic (B1)	3.04543	$PM_{2.5}$ =-255935.803(B1)^3 +10249.551 (B1) + 834.356
19/02/2020	Surface Reflectance	Quadratic(B1)	3.06305	$PM_{2.5}$ =-97904.134 (B1)^2 +41846.647(B1) -4406.375
	AOT	Cubic (B1)	1.71855	$PM_{2.5}$ =-11830.751(B1) -2495.359
22/03/2020	Surface Reflectance	Quadratic(B5)	0.55768	$PM_{2.5}$ =4088.126(B5)^2 +1848.642(B5) +222.103
	AOT	Quadratic(B5)	0.39297	$PM_{2.5}$=27376.867(B5)^2 +5077.45(B5) +248.168
23/04/2020	Surface Reflectance	Cubic (B2)	1.08604	$PM_{2.5}$ =580.987 (B2)^3-440.229(B2) +162.962
	AOT	Cubic (B7)	1.44927	$PM_{2.5}$ =272.930(B7)^2-233.65(B7) +64.957

From the $PM_{2.5}$ prediction through $PM_{2.5}$ map, it can be used to formulate the guidance standards in accordance with the environmental laws of $PM_{2.5}$ emission from industrial areas. Moreover, from the point of origin of the industrial plant Industrial estate and industrial areas, it should set the amount of dust accumulated in the atmosphere in addition to the announcement of the Ministry of Industry.

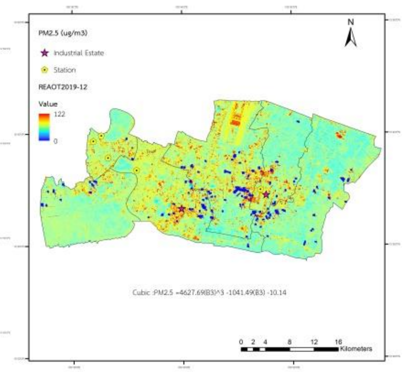
The study results found that satellite imagery can be used to map the concentrations of $PM_{2.5}$. From $PM_{2.5}$ map interpreted from the satellite results, $PM_{2.5}$ sources can be initially determined from the industrial area, leading to the formulation of standards in accordance with environmental laws. In addition, the map shows the measurement points of the ground monitoring stations of the Pollution Control Department. It was found that ground monitoring stations should be added to industrial sites in order to prevent problems in detecting the source of pollution and impact on the public warning about the accumulated $PM_{2.5}$ concentration, resulting in direct impact on public health in both the short and long.



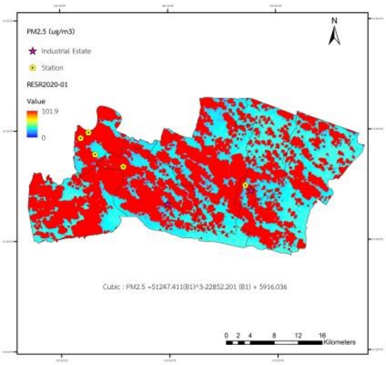
30/10/2019 (RMSE=0.90369)



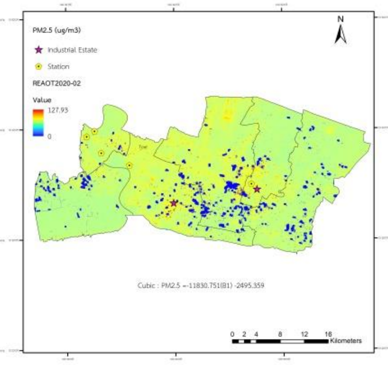
15/11/2019 (RMSE=0.94373)



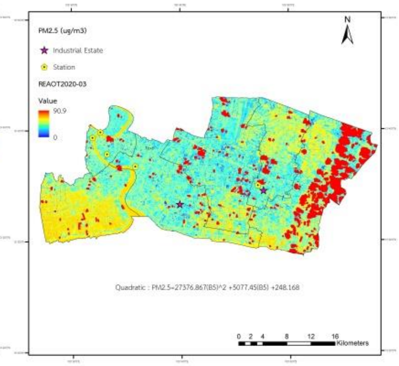
17/12/2019 (RMSE=1.78887)



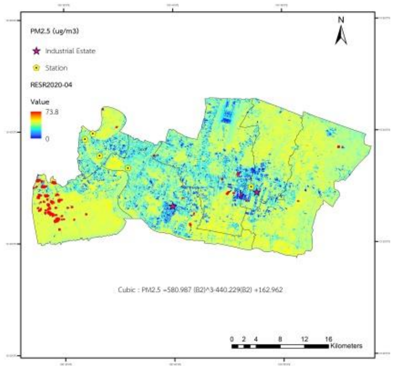
18/01/2020 (RMSE=1.08590)



19/02/2020 (RMSE=1.71855)



22/03/2020 (RMSE=0.39297)



23/04/2020 (RMSE=1.08604)

Figure 5 Map of dust particles smaller than 2.5 microns from the forecast from October 2019 to April 2020 in the Samut Prakan area

Conclusions

The prediction of $PM_{2.5}$ concentration by using mathematical models was based on correlation analysis of satellite imagery with collected data from the ground monitoring station in the Samut Prakan area from October 2019 to April 2020. The study results indicated that satellite imagery could be used to produce $PM_{2.5}$ map. The suitable equation model for predicting $PM_{2.5}$ concentration was Cubic equation ($Y= b_0+b_1X+b_2X^2+b_3X^3$), which yielded the greatest R^2 value of 0.959 of the correlation with surface reflection data. In addition, the Quadratic equation ($Y= b_0+b_1X+b_2X^2$) provided the greatest R^2 value, 0.968 based on the AOT correlation analysis, indicating very accurate performance. The lowest RMSE value was 0.39 when using the surface reflection data and the lowest RMSE value was 0.90 of the relative optical thickness data (AOT). The analytic results lead to the recommendations that the law enforcement agencies should analyze the emission of $PM_{2.5}$ concentration of industrial sector and formulate the standards in accordance with environmental laws.

In this regard, additional impact factors should be studied such as wind direction, relative humidity, rainfall, temperature, etc. in future studies so that PM2.5 predictive results will be more accurate. In addition, other ground monitoring stations in the industrial area should be explored, allowing an advance warning of the impact of $PM_{2.5}$ in a timely manner.

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