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Linear Regression Model for Predicting Daily $PM_{2.5}$ Using VIIRS-SNPP and MODIS-Aqua AOT

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Abstract. Small-sized particulates ($PM_{2.5}$) are very dangerous if inhaled by humans. The measurement of the particle concentration is carried out by the highly variable AQMS. Several studies have shown a positive relationship between aerosol optical thickness to surface $PM_{2.5}$. The study aims to predict $PM_{2.5}$ from Aerosol Optical Thickness using Linear Regression Model in Indonesia. The aerosol optical thickness is obtained from the VIIRS sensor on the SNPP satellite and from the MODIS sensor on the Aqua satellite. Linear regression model for predicting daily $PM_{2.5}$ using AOT VIIRS SNPP is $PM_{2.5}$=56.683*AOT-3.807 with r=0.7. Linear regression model for predicting daily $PM_{2.5}$ using AOT MODIS-Aqua is $PM_{2.5}$=104.3*AOT+1.0118 with r=0.7.

Keywords : AOT, VIIRS, MODIS, SNPP.

1. Introduction

Particulate matter (PM) or, more appropriately, the atmospheric aerosol is a multi-phase system of solid and liquid particles suspended in the air with aerodynamic diameters ranging from 10^{-3} μm–10 μm and includes both the particles and the air. Typically, the small solid and liquid particles are regarded as aerosols [1]. Aerosols have an important influence on atmospheric visibility, the radiation budget of the Earth-atmosphere system, the cloud-forming process, precipitation and human health.

Aerosol Optical Thickness is the degree to which aerosols prevent the transmission of light in the atmosphere. An aerosol optical thickness of less than 0.1 indicates a crystal-clear sky with maximum visibility, whereas a value of 4 indicates the presence of aerosols very dense so that people would have difficulty seeing the Sun, even at mid-day [2]. From an environmental standpoint, aerosols also constitute an important policy issue in air quality and climate sciences. In fact, PM pollution is probably the most pressing issue in air quality regulation worldwide, but at the same time it represents one of the biggest sources of uncertainty in current climate simulations. [3]

A reduction in long-term exposure to PM_{10} and $PM_{2.5}$ would have postponed 8% to 9% of all-cause mortality or about 37,000 deaths. One-third of them were associated with cardiopulmonary mortality and one-ninth of them were associated with lung cancer mortality. Current air pollution levels in Southeast and East Asian countries (including Indonesia) have a non-negligible public health impact.[4]

Many studies discuss the differences between aerosol properties as measured locally by surface stations and the large-scale ones measured by satellites. [5] Numerous researchers have attempted to estimate ground $PM_{2.5}$ levels using satellite-derived atmospheric aerosol optical depth. There are several approaches to estimate $PM_{2.5}$ from AOD, namely statistical approach, model scaling, and data assimilation. [6] Multiple linear regression (MLR) [7], mixed-effect model (MEM) [8], chemistry transport model (CTM) [9], and geographically weighted regression (GWR) [10] were the models most commonly used to predict $PM_{2.5}$. [10]

Remote sensing of $PM_{2.5}$ in Indonesia has not been studied yet. Our research aims to predict $PM_{2.5}$ concentration from aerosol optical thickness observed by satellite and $PM_{2.5}$ in situ relationship with the linear regression model in Indonesia. The $PM_{2.5}$ concentration spatial map will provide pollutant information in monitor sparse regions.

2. Data and Methods

2.1. Data

This study used three data sources. First is $PM_{2.5}$ concentration data recorded by Air Quality Monitoring System in three stations (figure 1): Pekanbaru1 (0°31'21" N 101°28'34" E), Pekanbaru2 (0°31'18" N 101°26'31" E), and Pekanbaru3 (0°27'54" N 101°23'15" E). Temporal resolution is half hourly. Pekanbaru City is a city located in Riau Province. The Riau region is very vulnerable to land fires. Pekanbaru City people experience health problems due to the highest smoke haze. But compared to other Riau regions, if seen from its geographical location, it is not possible to burn forests in pekanbaru City which can cause haze of forest fires. [11]

The second data source is Aerosol Optical Thickness from VIIRS which can be downloaded from ftp://ftp.star.nesdis.noaa.gov/pub/smcd/jhuang/npp.viirs.aerosol.data/edraot550 with spatial resolution 0.1° and temporal resolution is daily. Aerosol Optical Thickness (AOT), providing a measure of the aerosol content of the atmospheric column. The NASA/NOAA Visible Infrared Imaging Radiometer Suite (VIIRS) sensor was launched 28 October 2011 on the Suomi National Polar-orbiting Partnership (SNPP) satellite in a near-circular, sun-synchronous, near-polar orbit. VIIRS was having an 840 km mean altitude, 98.7° inclination, an orbital period of 101.5 min, and a nominal ascending equator local crossing time of 13:30 ±10 min. [12].

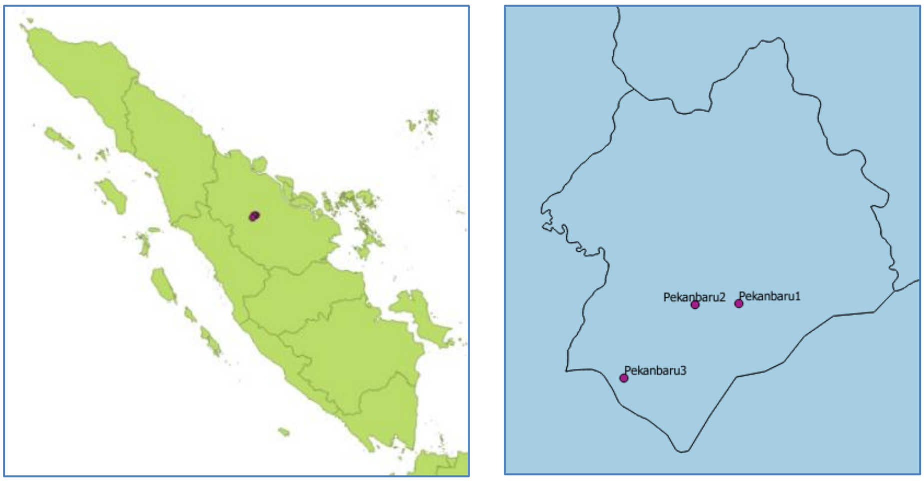


Figure 1 Three AQMS in situ Stations: Pekanbaru1, Pekanbaru2, Pekanbaru3.

The third data source is Aerosol Optical Depth or Thickness from MODIS which can be downloaded from https://ladsweb.modaps.eosdis.nasa.gov/. The MODIS instrument is a highly sensitive radiometer operating onboard Terra and Aqua. Aqua has a 1:30 am/pm equator crossing time while Terra has a 10:30 am/pm equator crossing time, meaning that MODIS data is typically available on a daily basis. Daily Level 2 (MOD 04) data are produced at the spatial resolution of a 10 x 10 1-km (at nadir) pixel array. This study used Aqua product only (MYD04_L2). MODIS bias that occurs in the aerosol optical thickness data set can be found in [13]. Validated against ground-based measurements, some studies have suggested that MODIS can retrieve aerosol optical depth with good accuracy over the ocean and has some skill over land. [14] Note that aerosol optical thickness and aerosol optical depth (τ) are used interchangeably to describe this data set.

2.2 Methods

This study used Linear Regression methods to produce mathematics model to predict $PM_{2.5}$ concentration using Aerosol Optical Thickness data (figure 2). To get the prediction model, AOT must be collocated with $PM_{2.5}$ in situ data averaging at 13:00, 13:30, and 14:00 adjusted satellite overpass. Regression analysis provides the first approximation of surface $PM_{2.5}$ mass concentration and air quality and it works best when the boundary layer is well mixed, there is no significant aerosol aloft, and in small particle dominated regions.

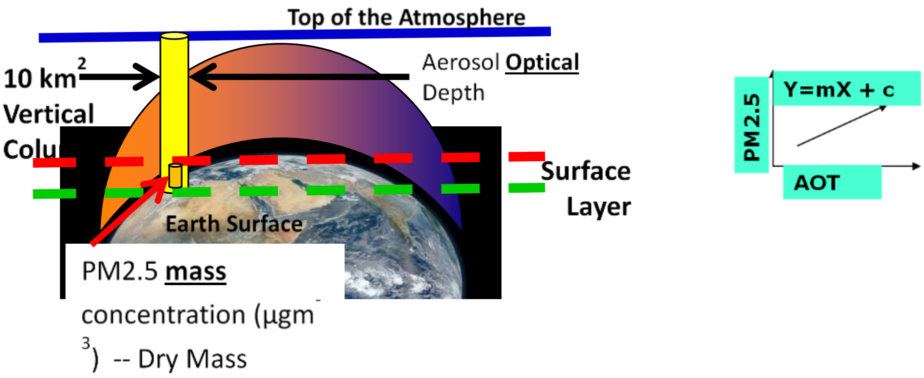


Figure 2 Illustration of predicting daily $PM_{2.5}$ using AOT data.

To plot, map, and collocate all data, we used Python version 3.6 and GrADS. To get 'closest distance' in collocating data, we used the Haversine Formula. [15, 16]

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2) \quad (1)$$

$$c = 2 \cdot \mathrm{atan2}\left(\sqrt{a}, \sqrt{(1-a)}\right) \quad (2)$$

$$d = R \cdot c \quad (3)$$

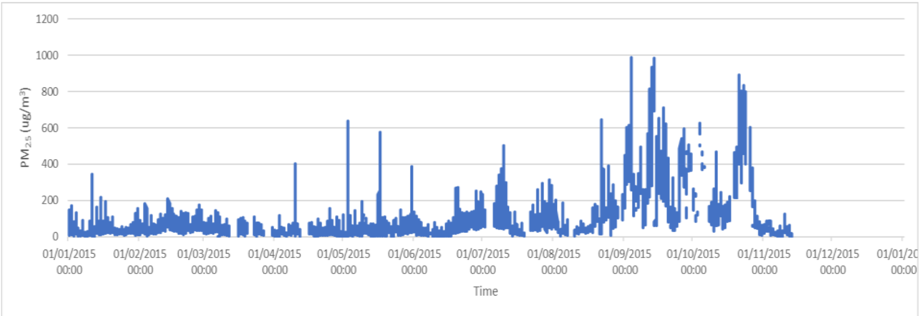
where φ is latitude, λ is longitude, R is earth's radius (mean radius = 6,371 km).

In addition, the effect of different AOD sampling box sizes was studied. The box size was 3 by 3 and 5 by 5 MODIS pixels, whose size is 10 km x 10 km.

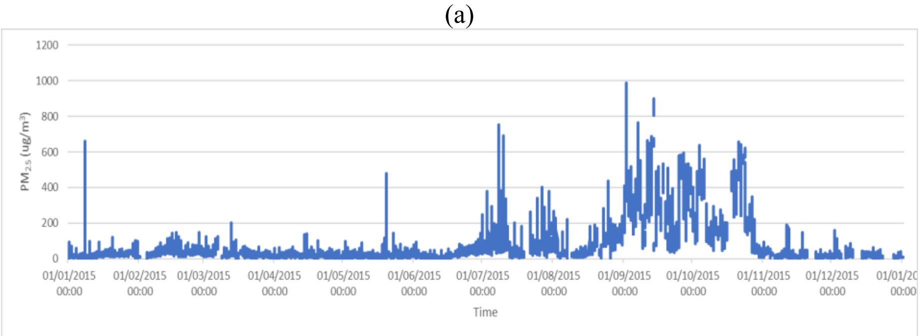
3. Results and Discussions

3.1. $PM_{2.5}$ and Aerosol Optical Thickness

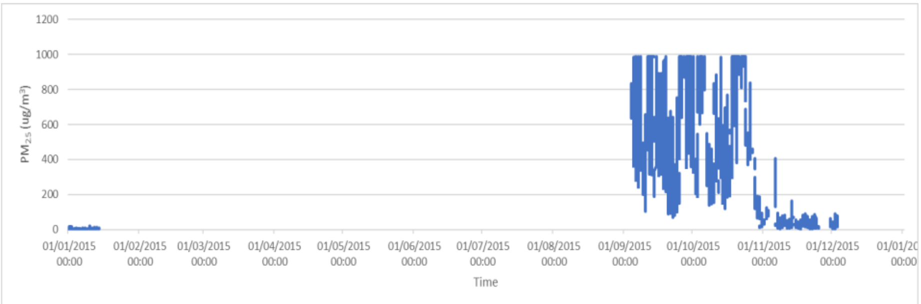
$PM_{2.5}$ concentration half hourly time series recorded in three stations from 1 January 2015 00:00 until 31 December 2015 23:30 were shown in figure 3. Both three stations showed very high $PM_{2.5}$ concentration in September – October as biomass burning result.



(a)



(b)



(c)

Figure 3 $PM_{2.5}$ concentration (μg/m^3) in situ half-hourly time series (1 January 2015 00:00 to 31 December 2015 23:30) in three stations: Pekanbaru1 (a), Pekanbaru2 (b), and Pekanbaru3 (c).

Aerosol Optical Thickness time series from 1 January until 31 December 2015 was shown in Figure 4. On September – October 2015, SNPP cannot detect AOT may be because of the existence of very thick smoke then satellite had difficulty in differentiating between cloud and smoke. The highest AOT recorded by VIIRS on September 22, 2015, amounted to 1.53 and was the peak of forest fires that hit Sumatra. Subsequent high-value AOT occurs on 20, 24 and 30 August 2015, which is around 1.4 which is the initial period of forest fires. AOT at Pekanbaru 1 Station were highest recorded by VIIRS on September 22, 2015 at 1.53 and was the peak of forest fires that hit Sumatra. Subsequent high-value AOT occur on 20, 24 and 30 August 2015, which is around 1.4 which is the initial period of forest fires. While at Pekanbaru 2 Station, the highest aerosol was found on August 31, 2015 at 1.18. Then at Pekanbaru 3 Station, the maximum AOT occurred on August 20, 2015 at 1.62.

During 1 January to 31 December 2015 (365 days), VIIRS-SNPP only detected AOT for 68 days in Pekanbaru1 (18.6%); 53 days in Pekanbaru2 (14.5%); and 66 days in Pekanbaru3 (shown in Figure 4). Compared with MODIS-Aqua (not shown), VIIRS-SNPP detects more AOT than MODIS-Aqua. It may be because of VIIRS scan wider and fewer gaps than MODIS. MODIS-Aqua only detected AOT for 15 days in Pekanbaru1 (4.12%); 11 days in Pekanbaru2 (3%); and 12 days in Pekanbaru3 (3.3%).

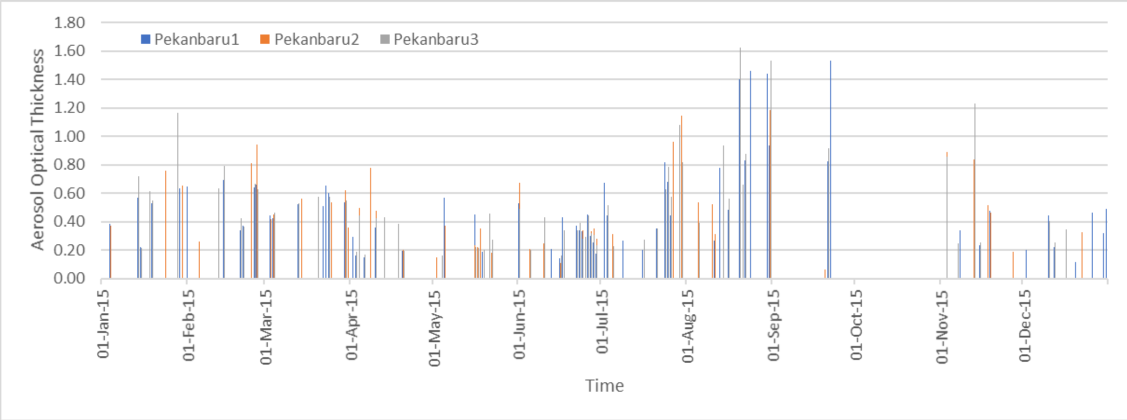


Figure 4. Aerosol Optical Thickness daily time series observed by VIIRS-SNPP (1 January 2015 to 31 December 2015) in three locations: Pekanbaru1 (a), Pekanbaru2 (b), and Pekanbaru3 (c).

3.2. Linear Regression Model

Scatter plots between $PM_{2.5}$ concentration (AQMS) and Aerosol Optical Thickness (VIIRS-SNPP) are shown in Figure 5. This figure was produced by collocating $PM_{2.5}$ and AOT between in situ locations with VIIRS SNPP regularly spaced data (gridded) coordinates. The correlation coefficient between $PM_{2.5}$ and AOT for three sites: 0.8 (Pekanbaru1) with 47 data pairs, 0.75 (Pekanbaru2) with 45 data pairs, and 0.6 (Pekanbaru3) with 4 data pairs. For all data pairs by combining Pekanbaru1, Pekanbaru2, and Pekanbaru3 data, the correlation coefficient between $PM_{2.5}$ and AOT is 0.7. Linear regression model for predicting daily $PM_{2.5}$ using AOT VIIRS SNPP is $PM_{2.5}$=56.683*AOT-3.807.

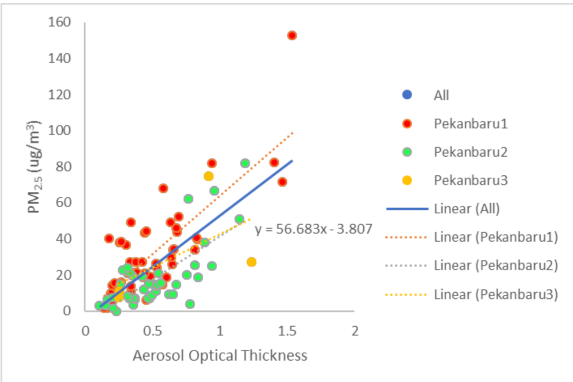
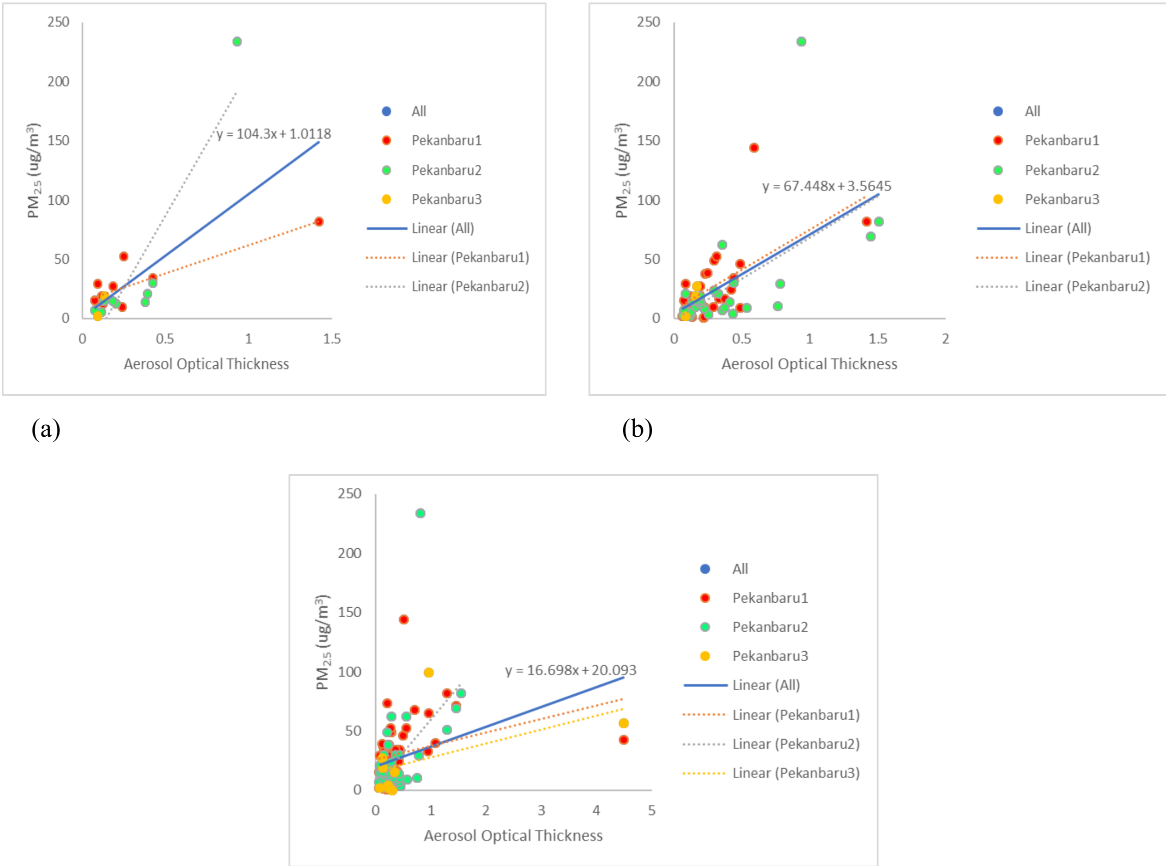


Figure 5. Scatter plot $PM_{2.5}$ concentration in situ collocated with AOT VIIRS SNPP in three sites: Pekanbaru1, Pekanbaru2, and Pekanbaru3 from 1 January to 31 December 2015.

Scatter plots between $PM_{2.5}$ concentration (AQMS) and Aerosol Optical Thickness (MODIS-Aqua) are shown in Figure 6. Figure 6a was produced using "closest distance" to collocate between in situ locations with MODIS-Aqua coordinates in radius 10 km. The correlation coefficient between $PM_{2.5}$ and AOT for two sites: 0.85 (Pekanbaru1) with 10 data pairs and 0.9 (Pekanbaru2) with 10 data pairs. Another site (Pekanbaru3) only had 2 data pairs then correlation coefficient was not computed. Figure 6b was produced using average values in "radius 3x10 km". The correlation coefficient between $PM_{2.5}$ and AOT for two sites: 0.6 (Pekanbaru1) with 24 data pairs and 0.58 (Pekanbaru2) with 28 data pairs. Another site (Pekanbaru3) only had 3 data pairs then the correlation coefficient was not computed. Figure 6c using average values in "radius 5x10 km". The correlation coefficient between $PM_{2.5}$ and AOT for three sites: 0.3 (Pekanbaru1) with 53 data pairs, 0.5 (Pekanbaru2) with 52 data pairs, and 0.5 (Pekanbaru3) with 9 data pairs. Wider radius (30 km and 50 km) will add the number of $PM_{2.5}$ and AOT pairs but not increasing correlation coefficient.



(a) (b)

(c)

Figure 6. Scatter plot $PM_{2.5}$ concentration in situ collocated with AOT MODIS Aqua in three sites: Pekanbaru1, Pekanbaru2, and Pekanbaru3 during 1 January to 31 December 2015 using three different methods: **a)** closest distance (radius 10 km), **b)** radius 3x10 km, and **c)** radius 5x10 km.

For all data pairs by combining Pekanbaru1, Pekanbaru2, and Pekanbaru3 data, the correlation coefficient for three methods: 0.7 (closest distance with 22 data pairs), 0.6 (radius 3x10 km with 55 data pairs), and 0.3 (radius 5x10 km with 114 data pairs). These results are different from the results of previous studies which showed that AOD does not change remarkably as a function of box size around their study area. [17] Then we suggest to use closest distance methods and results linear regression model for predicting daily $PM_{2.5}$ using AOT MODIS-Aqua is $PM_{2.5}$=104.3*AOT+1.0118.

4. Conclusion

Both aerosol optical thickness from MODIS-Aqua and VIIRS-SNPP can be used to predict daily $PM_{2.5}$ concentration with correlation coefficient 0.7. The formula to predict $PM_{2.5}$ from VIIRS-SNPP AOT is $PM_{2.5}$=56.683*AOT-3.807. The formula to predict $PM_{2.5}$ from MODIS-Aqua is $PM_{2.5}$=104.3*AOT+1.0118. To improve the accuracy of predictions, we should add the number of $PM_{2.5}$ and AOT pairs.

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