

Real Time Assessment of Haze and PM₁₀ Aided by MODIS Aerosol Optical Thickness over Klang Valley, Malaysia

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Abstract: Scarcely distribution, installation and maintenance costs for ground monitoring stations are issues in air pollution monitoring. Moderate resolution imaging Spectroradiometer (MODIS) on board of Terra and Aqua satellites is able to retrieve aerosol optical thickness (AOT) in troposphere and can be utilized in particulate matter pollution monitoring. In this study, daily AOT data retrieved from MODIS in 2004 to 2006, using Non-linear correlation coefficient (NLCC) were compared with the amount of particulate matter PM₁₀ measured at eight ground air quality monitoring stations in Klang Valley, Malaysia. Effects of haze on air quality that indicated MODIS AOT before, during and after the severe haze were also studied. Results showed that the air quality conditions in dry season are unhealthy and correlation coefficients between MODIS AOT and PM₁₀ concentration are higher than those in rainy season. The corresponding AOT change during the rainy season was between lower than 0.1 and 2.5. It shows that for the rainy season it is less than 0.1. This study reveals AOT data from MODIS can be utilized to study the air quality, especially PM₁₀ in the places where there are not any ground measurements.

Key words: MODIS • Air quality • Season • Troposphere • Correlation coefficient

INTRODUCTION

The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Aqua and Terra satellites is part of the NASA-centered international Earth Observing System (EOS) [1]. Aerosol optical thickness (AOT) from MODIS data represents columnar aerosol loading from the surface to the top atmosphere [2]. Several studies on the relationship between particulate mass concentrations which measured by ground stations and satellite-derived AOT had been undertaken [3-6]. Some studies presented the determination of forest fire smoke using MODIS data [7-9]. During bushfire, corresponding AOT changes increased from less than 0.1 before bushfire to greater than 1.0 [8]. Therefore they concluded that satellite data are an excellent tool for studying PM air quality over large area. This paper emphasize on assessment of haze and particulate matter using the remote sensing techniques. Thus, two main objectives of this paper are: (i) to determine the value of correlation coefficients between

annually and seasonally PM₁₀ mass in the air and AOT derived from Terra-MODIS at different locations in the Klang Valley in 2004 and 2006; and (ii) to determine the effect of haze on PM air quality and MODIS AOT before, during and after the severe haze from July to August 2005.

MATERIALS AND METHODS

Klang Valley is a part of Selangor and is located in the central part of the west coast of Peninsular Malaysia. Klang Valley delineated by Strait of Malacca to the west, the Titiwangsa Mountains to the north and east, this region is located in a bowl-like topography. There are 8 monitoring stations in Klang Valley (Figure 1). The RGB images before, during and after the severe haze were geo-referenced in PCI Geomatica version 9.1. Images were converted to Arc GIS version 9.2 for presentation purpose. The MODIS level 2 daily AOT products at 0.55 μm wavelength from Terra (MYD04_L2 is specifically devoted to aerosol studies)

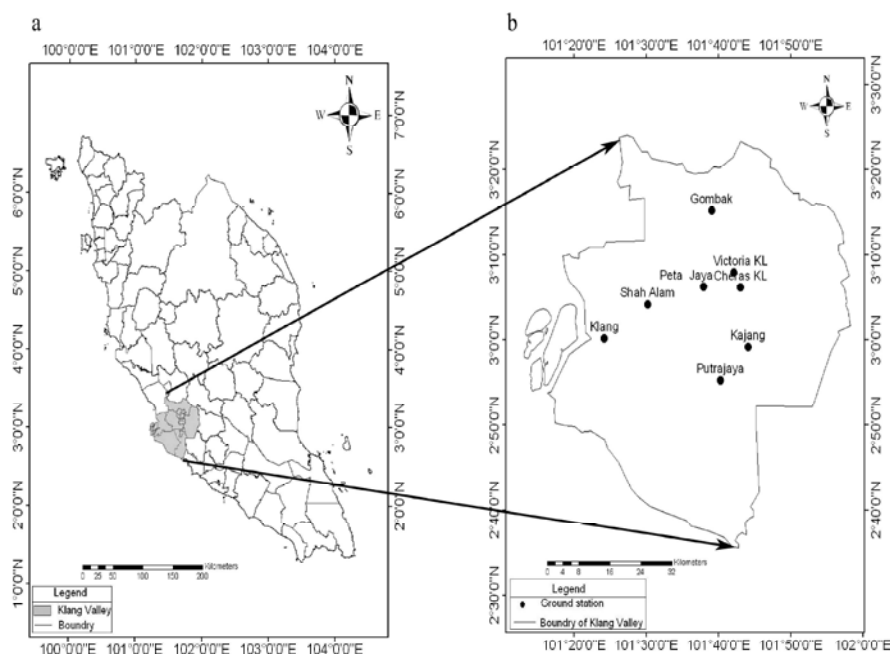


Fig. 1: Ground stations network which measures PM_{10} mass concentration in Klang Valley

from 2004 to 2006 were downloaded (<http://ladsweb.nascom.nasa.gov/data/search.html>) according to geographical coordinates of the ground stations in Klang Valley. The format of data file is hierarchical data format (HDF) which comprises the text files, charts and tables (NASA, 2009). PM_{10} data and Geographical coordinates were viewed in HDF file using HDF explorer. Data validations were analyzed by comparing MODIS AOT and real-time of ground stations using Non-linear regression. Each pixel of level 2 AOT product has a 10×10 km resolution. To take corresponding data pixel from AOT and coordinate tables, macro was used in MS Excel. Visual basic program was written for running the model in macro. The data from each table (Longitude, latitude and PM_{10} data) were arranged in a column in MS Excel. As result, pixel data in all tables were arranged in a row. To determine the coordinates situated inside study area another Visual basic program was written MODIS pixels are found to be more reliable when the 50×50 km² (5×5 pixels) average over PM_{10} stations is used [10]. The number of MODIS AOT data pixels for averaging over PM_{10} stations should be at least three [8]. Malaysian Ambient Air Quality Standards MAAQS comprising daily and annual standards for PM_{10} . According to these standards, the amount of PM_{10} should be less than $150\mu\text{g}/\text{m}^3$ on daily basis and the monthly mean should be less than $50\mu\text{g}/\text{m}^3$.

RESULT AND DISCUSSION

Haze and Modis AOT: Haze events in south-east Asia were recorded in 1983, 1990, 1994 and 1997 [11, 12]. Each year, Malaysia experienced short or long term of moderate intense haze especially in dry season. For example, in 1997 [13], 1999 and 2000 [14], slight haze in 2004 and 2006 [15 and 16] and intense haze in 2005 [17]. Farmers in island of Sumatra, Indonesia, burn the scrub and forest to clear land, which aggravated the haze problem especially during the dry season. As a result, the eastern and northern parts of Peninsular Malaysia experienced severe haze from 1 August 2005 to 15 August 2005 [17]. The AOT at $0.55 \mu\text{m}$ before (22 July 2005), during (8 August 2005) and post-fire (21 August 2005) days are presented in Figure 2. Figure 2b shows a strikingly high value of AOT compared to Figure 2a-c. AOT values of more than 1 are considered haze pixel and assigned red. The AOT values derived on 22 July showed low (Figure 2a) and the AOT values derived on 8 August (during the peak of haze) showed high value (Figure 2b). The post-haze AOT map on 21 August showed the high AOT values during the haze had dropped to normal level (Figure 2c).

The effect of haze on the increase of aerosol loading between 3 August and 14 August 2005 in Gombak is shown in Figure 3. Both PM_{10} mass concentration and AOT values were low from 23 July to 3 August and

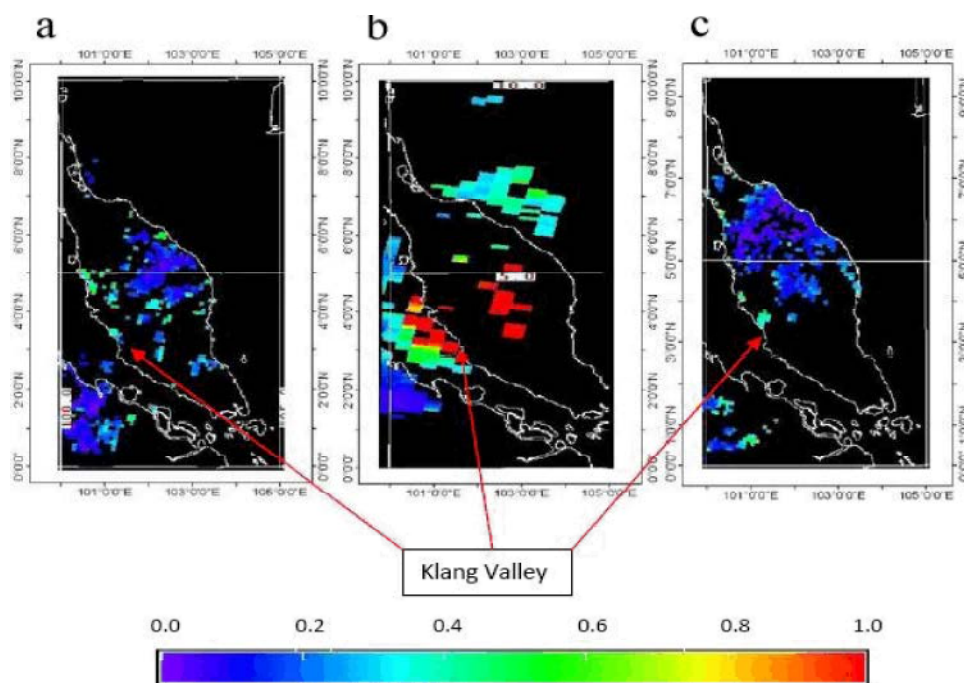


Fig. 2: Haze in Klang Valley and surrounding area as observed from MODIS sensor. (a) Shows the AOT values retrievals in 22 July 2005 before haze. (b) AOT values in 8 August 2005 during the haze. (c) AOT values in 21 August 2005 after the haze.

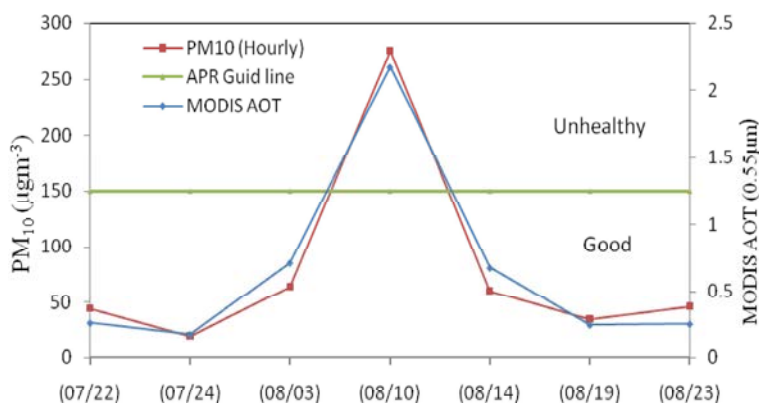


Fig. 3: Effect of haze on air quality and MODIS AOT over Gombak station during 22 July to 23.

air quality was in a good condition. As haze started in the area, the PM_{10} increased more than a 400% and AOT increased to more than a 300% within 10 days from 3 August to 13 August 2005. According to these findings, both the ground measurement and the AOT values show similar trends.

Relationship Between PM_{10} Mass and MODIS AOT:

The p -value of data is an important in any regression analysis. The p -value lowers than 0.05 means that there is a great deal of confidence and the coefficient is truly different from zero and linear correlation result is acceptable and vice versa. In addition, weak result of linear regression caused uses the Non-linear which is the

reason of use it's in this study. As result, the Non-linear correlation coefficient using polynomial equation was used to evaluate for any correlation between MODIS AOT and hourly PM_{10} mass in eight AQMS in Klang Valley (Table 1). The lowest and highest NLCC were obtained at Petaling Jaya at 0.37 and Kajang at 0.66 respectively. The highest and lowest NLCC were acquired from 0.43 and 0.38 AOT means. There is no distinct relationship between amount of NLCCs and AOT means. For example, the second highest NLCC 0.60 at Victoria K.L, was acquired from 0.32 AOT means which is the lowest AOT mean. On the other hand, the second lowest NLCC at Klang, were acquired also from 0.57 which is second highest AOT mean.

Table 1: Statistics of PM₁₀ mass concentration and MODIS AOT for 2004 and 2006 of eight AQMS in Klang Valley

Stations name	No. of points	Corr. Coeff (R ²)	PM ₁₀ (µgm ⁻³)				MODIS AOT (0.55µm)			
			Min	Max	Mean	SD	Min	Max	Mean	SD
Gombak	86	0.47	13	146	47.99	25.53	0.02	1.77	0.44	0.38
Klang	32	0.43	10	109	62.84	42.05	0.13	2.06	0.57	0.49
Victoria Kuala Lumpur	27	0.60	3.8	132	59.14	37.12	0.03	0.98	0.32	0.37
Petaling Jaya	54	0.37	14	123	50.50	19.10	0.04	1.69	0.38	0.41
Kajang	41	0.66	9	142	46.54	25.82	0.08	1.83	0.43	0.38
Shah Alam	47	0.57	19	144	56.70	24.48	0.04	2.50	0.64	0.49
Putra Jaya	30	0.59	13	142	49.06	23.54	0.08	1.85	0.55	0.45
Cheras Kuala Lumpur	50	0.57	21	140	55.28	22.42	0.03	1.69	0.45	0.40

Table 2: Seasonal statistics of PM₁₀ mass concentration and MODIS AOT for 2004 and 2006 of eight AQMS in Klang Valley.

Stations name	Dry season				Rainy season			
	No. of points	Corr. Coeff	PM10. Mean	MODIS AOT. SD	No. of points	Corr. Coeff	PM10. Mean	MODIS AOT. SD
Gombak	59	0.58	47.28	0.42	27	<0.100	34.22	0.27
Klang	21	0.78	88.90	0.49	11	<0.100	46.45	0.43
Victoria Kuala Lumpur	20	0.70	47.10	0.41	7	0.241	30.68	0.12
Petaling Jaya	40	0.45	53.67	0.41	14	0.150	41.64	0.33
Kajang	32	0.66	52.10	0.41	9	0.121	35.00	0.09
Shah Alam	36	0.77	62.47	0.48	11	<0.100	38.72	0.44
Putra Jaya	23	0.76	55.73	0.43	7	0.473	26.71	0.48
Cheras Kuala Lumpur	36	0.60	56.16	0.42	14	0.311	42.71	0.31

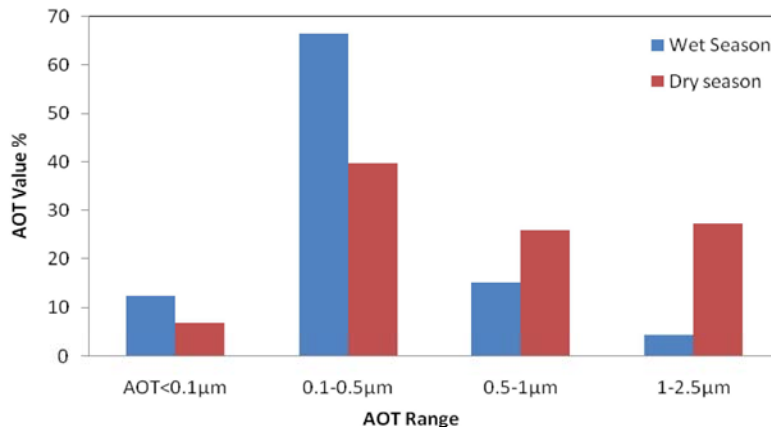


Fig. 4: Effects of air poor quality condition in dry season and good air quality condition in rainy season on MODIS AOT in Klang Valley

The NLCC value was found to be low for Petaling Jaya and Klang as compared to other sites. Petaling Jaya and Klang has a higher number of industrial units in Klang Valley in comparison with the other sites, which might have been the reason behind the highest sulfur dioxide (SO₂) observed in Petaling Jaya and Klang. SO₂ can be transformed to sulfate in the atmosphere. Generally sulfate particles have higher light extinction efficiency than carbonaceous particles especially under high relative humidity conditions [17]. Therefore, AOT value increases

more than the real range and the NLCC decreases. NLCC were also performed to determine relationship between satellite observations and PM₁₀ mass during in dry and rainy seasons (Table 2). In all stations MODIS AOTs are strongly correlated in dry season compared rainy season. The NLCC value in Klang was reported 0.78 in dry season but below 0.1 in rainy season. The high amount of PM₁₀ in dry season increased the MODIS AOT value from 1 to 2.5 levels (Figure 4). In rainy season 94% and dry season 72% of MODIS AOT was observed between 0.1 and 1.

MODIS AOTs were most suitable when the amount of PM₁₀ was high at ground stations (Table 2). This study reveals that a high NLCC value, a poor air quality and a low NLCC value are obtained when the air quality is good. Concentration of air particulate matter in Malaysia and Southeast Asia is influenced by the southwest monsoon wind and the occurrence of biomass burning [18]. Transportation of haze from forest fire Sumatra [13], seasonal variations of 'El Niño' modulations and regional low level winds are the main reasons of poor air quality conditions during dry season in Klang Valley. During rainy season, the moisture and cloud cover are higher than dry season. Increasing moisture in the air may swell the hygroscopic particles, or condensate hydrophobic particles. Cloud cover may also transport the gases and particulate matter from the mixing layer to free troposphere. Thus, in rainy season, there will be large differences between the measurements recorded by ground stations as compared to those recorded by satellite.

CONCLUSIONS

In Klang Valley, Haze has caused the PM₁₀ mass concentration to increase more than 4 times and AOT more than 3 times in comparison with the periods before and after the haze. The lowest and highest annual NLCC were obtained in Petaling Jaya (0.37) and Kajang (0.66) respectively. Correlation coefficient between MODIS AOT and PM₁₀ mass concentration in dry season are higher than the rainy season. The amount of PM₁₀ in dry season is more than rainy season, indicating that when air quality is poor correlation coefficient value between AOT and PM₁₀ mass is high and when air quality condition is good the correlation coefficient is low. It can be concluded that MODIS aerosol retrieval algorithm might need a high amount of aerosol. MODIS has potential capability for monitoring PM air quality, where there are not enough ground measurements. Satellite data are able to recognize the regionally and distribution of SPM over large scale. Further studies are needed to describe the accuracy assessment of MODIS AOT level for Klang Valley.

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