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# Aerosol Optical Thickness and PM10 Study by Using a Handheld Spectroradiometer Over Penang

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## 1. Introduction

Knowledge of the parameters that are related to the optical properties of atmospheric aerosols is essential for the determination of their climatic effects, development of techniques for remote sensing of aerosol from space or the necessary correction of atmospheric effects in satellite imagery (Sanchez, et al., 1998). The AOT values were derived from the measured transmittance. AOT,  $\tau$ , is a measure of aerosol loading in the atmosphere (Christopher, et al., 2002). Generally, a higher AOT value indicates higher column of aerosol loading and therefore low visibility (Wang and Christopher, 2003).

Atmospheric components (aerosol and molecules) scatter and absorb solar radiation. This study investigated the use of a handheld spectroradiometer for the retrieval of atmospheric optical thickness (AOT) values over Penang Island. A set of spectroradiometer measured transmittance data was used to derive the aerosol optical thickness (AOT) in the atmosphere. The transmittance values were measured in spectral region from 350nm to 1050nm at the earth surface. The locations were determined with a Global Positioning System (GPS) receiver. We selected the values at 550nm for the present analysis. This study introduces an economical and a simple technique for retrieval of AOT for remote sensing application. The transmittance values were measured around the Penang Island. Particulate matters of size less than 10 micron (PM10) were collected simultaneously with the acquisition of the transmittance measurements. The results of the analysis indicated that the AOT values were linearly correlated with the PM10 readings.

The objective of this study was to explore the relationship between aerosol optical thickness (AOT) derived from the spectroradiometer transmittance measurements and the correlation of particulate matter less than 10 micron (PM10). PM10 values were collected simultaneously with the transmittance measurements. This study showed that there was a good correlation between the derived AOT and the measured PM10. In this study, we present results from ground-based measurements for PM10 mapping.

Many researchers have conducted satellite monitoring of the AOT [Husar, et al., (1997) and Liu, et al., (2002), Jiang, et al., (2007) and Guo, et al., (2009)]. In this study, we present a method for air quality mapping from ground-based measurements. Typically, ground based measurements were made with a device of sun photometer. In this study, our purpose is to generate AOT and PM10 maps over Penang Island, Malaysia by using a handheld spectroradiometer. The transmittance values were measured using a handheld

spectroradiometer. The sensitivity of this type of spectroradiometer is between the spectral wavelengths from 350 nm to 1050 nm. The well known Beer-Lambert law was used in this study to retrieve AOT values from the transmittance value measurements. AOT and PM10 maps were generated using Kriging interpolation technique based on the measured data. This study indicates that the spectroradiometer is a useful tool for retrieval of AOT and PM 10 values in Penang, Malaysia

## 2. Study area

The study area is the Penang Island, Malaysia, located within latitudes  $5^{\circ} 9' N$  to  $5^{\circ} 33' N$  and longitudes  $100^{\circ} 09' E$  to  $100^{\circ} 30' E$ . The map of the study area is shown in Figure 1. Penang Island is located in equatorial region and enjoys a warm equatorial weather the whole year. Therefore, it is impossible to get the 100 % cloud free satellite image over Penang Island. But, the satellite image chosen is less than 10 % of cloud coverage over the study area. Penang Island located on the northwest coast of Peninsular Malaysia.

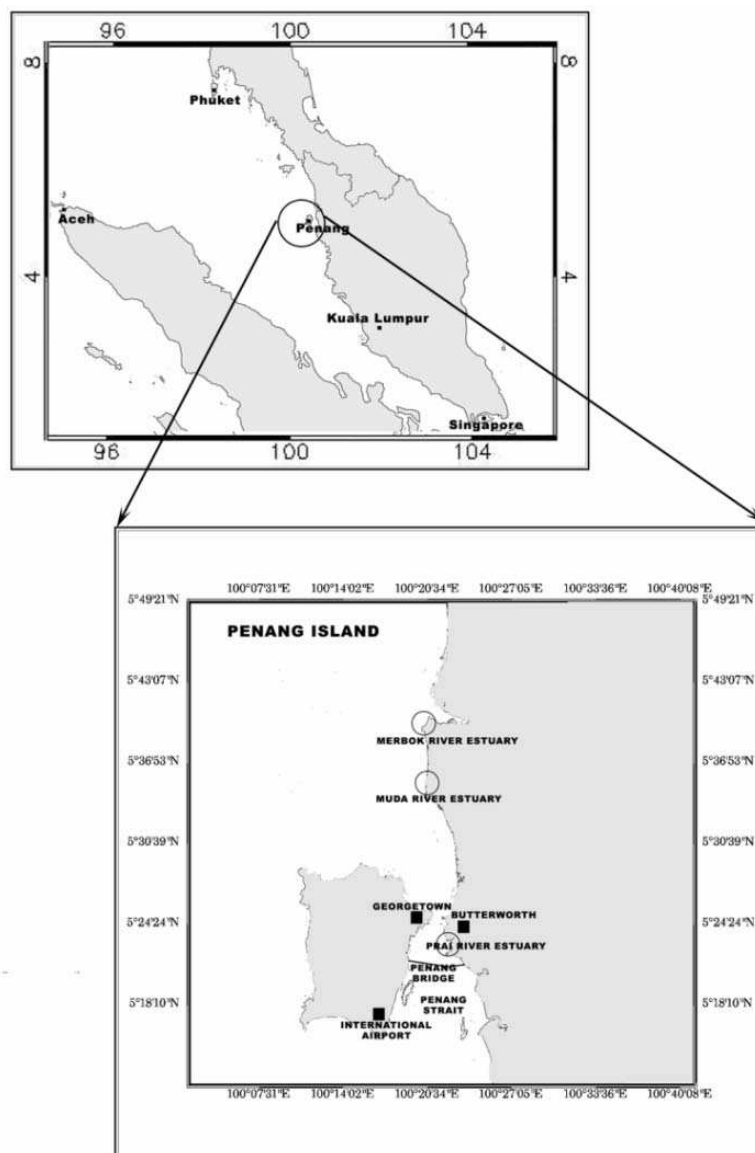


Fig. 1. The study area

Penang is one of the 13 states of the Malaysia and the second smallest state in Malaysia after Perlis. The state is geographically divided into two different entities - Penang Island (or "Pulau Pinang" in Malay Language) and a portion of mainland called "SeberangPerai" in Malay Language. Penang Island is an island of 293 square kilometres located in the Straits of Malacca and "SeberangPerai" is a narrow hinterland of 753 square kilometres (Tan, et al., 2010). The island and the mainland are linked by the 13.5 km long Penang Bridge and ferry. Penang Island is predominantly hilly terrain, the highest point being Western Hill (part of Penang Hill) at 830 metres above sea level. The terrain consists of coastal plains, hills and mountains. The coastal plains are narrow, the most extensive of which is in the northeast which forms a triangular promontory where George Town, the state capital, is situated. The topography of "SeberangPerai" is mostly flat. Butterworth, the main town in "SeberangPerai", lies along the "Perai" River estuary and faces George Town at a distance of 3 km (2 miles) across the channel to the east (Tan, et al., 2010).

The Penang Island climate is tropical, and it is hot and humid throughout the year. with the average mean daily temperature of about 27°C and mean daily maximum and minimum temperature ranging between 31.4°C and 23.5°C respectively. However, the individual extremes are 35.7°C and 23.5°C respectively. The mean daily humidity varies between 60.9% and 96.8%. The average annual rainfall is about 267 cm and can be as high as 624 cm (Tan, et al., 2010).

### 3. Data acquisition

The corresponding PM10 measurements were collected at the several selected locations around the Penang Island between 9.00 a.m. to 3.00 p.m. A handheld spectroradiometer was used to collect the sky transmittance data over Penang Island, Malaysia campus on 24th December 2008 from 40 stations in the USM campus (Fig. 2). The AOT was calculated based on the Beer-Lambert-Bouguer law. Table 1 shows the specification of the ASD handheld spectroradiometer used in this study.

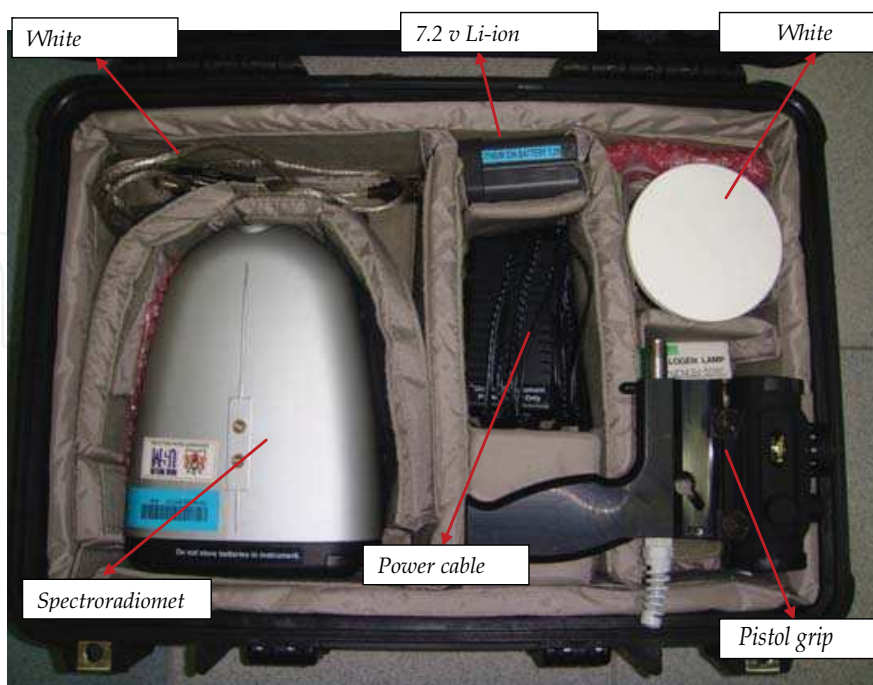


Fig. 2. The ASD handheld Spectroradiometer

<b>FieldSpec® HandHeld (325-1075nm)</b>	A field portable, lightweight, battery powered spectroradiometer.
<b>Spectral Range:</b>	325 - 1075 nm.
<b>Sampling Interval :</b>	1.6 nm.
<b>Spectral Resolution:</b>	3.5 nm at 700 nm.
<b>Noise Equivalent Delta Radiance (NeDL):</b>	$5.0 \times 10^{-9} \text{ W/cm}^2/\text{nm/sr} @ 700 \text{ nm.}$
<b>Weight:</b>	1.2 kg including battery pack.
<b>Size:</b>	22 x 16 x 8.2 cm.

Table 1. Specification of the ASD handheld Spectroradiometer

#### 4. Methodology

The transmittance data over Penang Island on 24th December 2008 was used in this study. The observation site is located in the northern region of the Peninsular Malaysia. The spectroradiometer measure the atmospheric transmittance from 350nm to 1050nm. The data that have been used in this study were collected at 40 locations in Penang, Malaysia.

The AOT is calculated based on the Beer-Lambert-Bouguer law. The AOT is related to the transmission by the expression

$$T_{d\lambda} = e^{-\frac{\tau_{\lambda}}{u_s}} \quad (\text{Vermote, et al., 1997}) \quad (1)$$

where

$T_{d\lambda}$  = transmittance for direct irradiance at wavelength,  $\lambda$

$u_s$  = cosines ( $\theta$ ),  $\theta$  is the zenith angle

AOT values were obtained after performing the sequence of the following calculations:

1. First, we measured the total solar irradiance. This was done by measuring the radiance reflected from a Spectralon panel placed perpendicular to the direction of the Sun. The measured radiance was converted into irradiance by multiplying by  $\Pi$  and then divided by the reflectance of the Spectralon panel.
2. Second, we measured the diffuse irradiance. This step was performed with the same Spectralon panel maintained in the same orientation as in step 1. The panel was shaded from direct sunlight using a disk of black painted cardboard mounted on a stick. The size of the disk and distance to the panel should be such that the shadow of the disk on the panel is just sufficient to fully shade the area viewed by the FieldSpec HH. As in step 1, we measured the reflected radiance. Again, the measured radiance is converted to irradiance by multiplying by  $\Pi$  and then dividing by the reflectance of the Spectralon panel.
3. Third, we computed the direct solar irradiance by subtracting the diffuse irradiance from the measured total solar irradiance.

- Fourth, we computed the top-of-atmosphere (TOA) solar irradiance values corresponding to the wavelengths of the spectra measured by the FieldSpec HH. In this study, Wehrli 1985 AM0 Spectrum was chosen to calculate the TOA spectra and interpolate it to the FieldSpec HH wavelengths, multiplying by cosines solar angle and then correct for the exact Earth-Sun distance factor,  $D$ , given by Spencer, 1971 as

$$D = 1.00011 + 0.034221 \cos \phi + 0.00128 \sin \phi + 0.000719 \cos 2\phi + 0.000077 \sin 2\phi \quad (2)$$

The day angle,  $\phi$ , in radians is represented by

$$\phi = 2\pi(d - 1) / 365 \quad (3)$$

where  $d$  is the day number of a year (1-365)

- Finally, we computed the atmospheric transmission by dividing the direct solar irradiance computed in step 3 by the top of atmosphere values calculated in the fourth step. This was done by first exporting the FieldSpec HH spectrum to a text file, importing the text file into a program like MS Excel and then performing the calculations in Excel. Then the AOT values were computed using Equation (1).

## 5. Data analysis and results

The transmittance values were measured using a handheld spectroradiometer. The sensitivity of this type of spectroradiometer is between the spectral wavelengths from 350 nm to 1050 nm. We selected 6 spectral wavelengths in this study centred at 400.5 nm, 500.5 nm, 600.5 nm, 700 nm, 800 nm and 900 nm. These selected 6 bands are based on the Wehrli 1985 AM0 Spectrum. Then the transmittance values were used to derive the AOT values using Equation (1). AOT maps were created using Kriging interpolation technique for estimating aerosol values to be associated to their distribution patterns (Figure 3).

In this study, we used PM10 as air quality parameter measurements over Penang Island. The relationship between AOT and PM10 was investigated in this study and we discovered that there was a linear relationship between PM10 and AOT. The linear correlation coefficient ( $R$ ) was greater than 0.8 (Figure 3). Several studies have indicated linear relationship between these parameter [Christopher and Wang, (2003) and Wang and Christopher, (2003)]. We can clearly see from Figure 4 that PM10 values was increasing as the AOT values increasing. Therefore AOT is a useful information for retrieval of PM 10 values.

From our experimental data set, we can see the PM10 increases as the AOT increases. This mean that as the AOT values increases these is an increase of the concentration of PM10. Therefore, we obtained a positive correlation between AOT and PM10. From the AOT and PM10 maps, we can see that the high concentration of the AOT and PM10 values was located near the Bayan Lepas and Prai industrial areas (Black circle) and Georgetown urban areas (Red circle) (Figures 3 and 5). This was due to the high density of population area and industrial area respectively. The air pollution caused by industry has even more grave effects than vehicle exhaust fumes

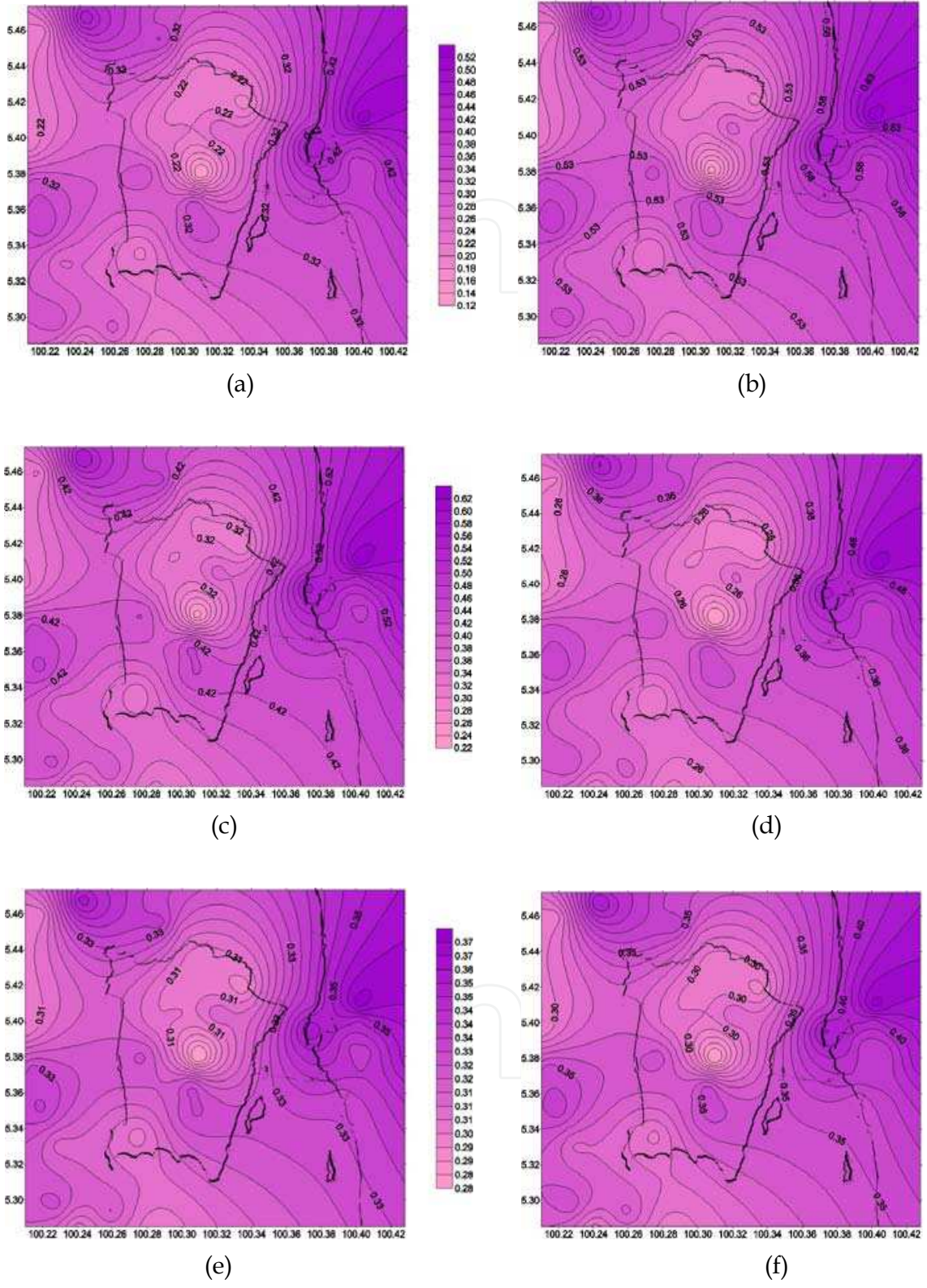


Fig. 3. AOT map for (a) 400.5 nm, (b) 500.5 nm, (c) 600.5 nm, (d) 700 nm, (e) 800 nm and (f) 900 nm

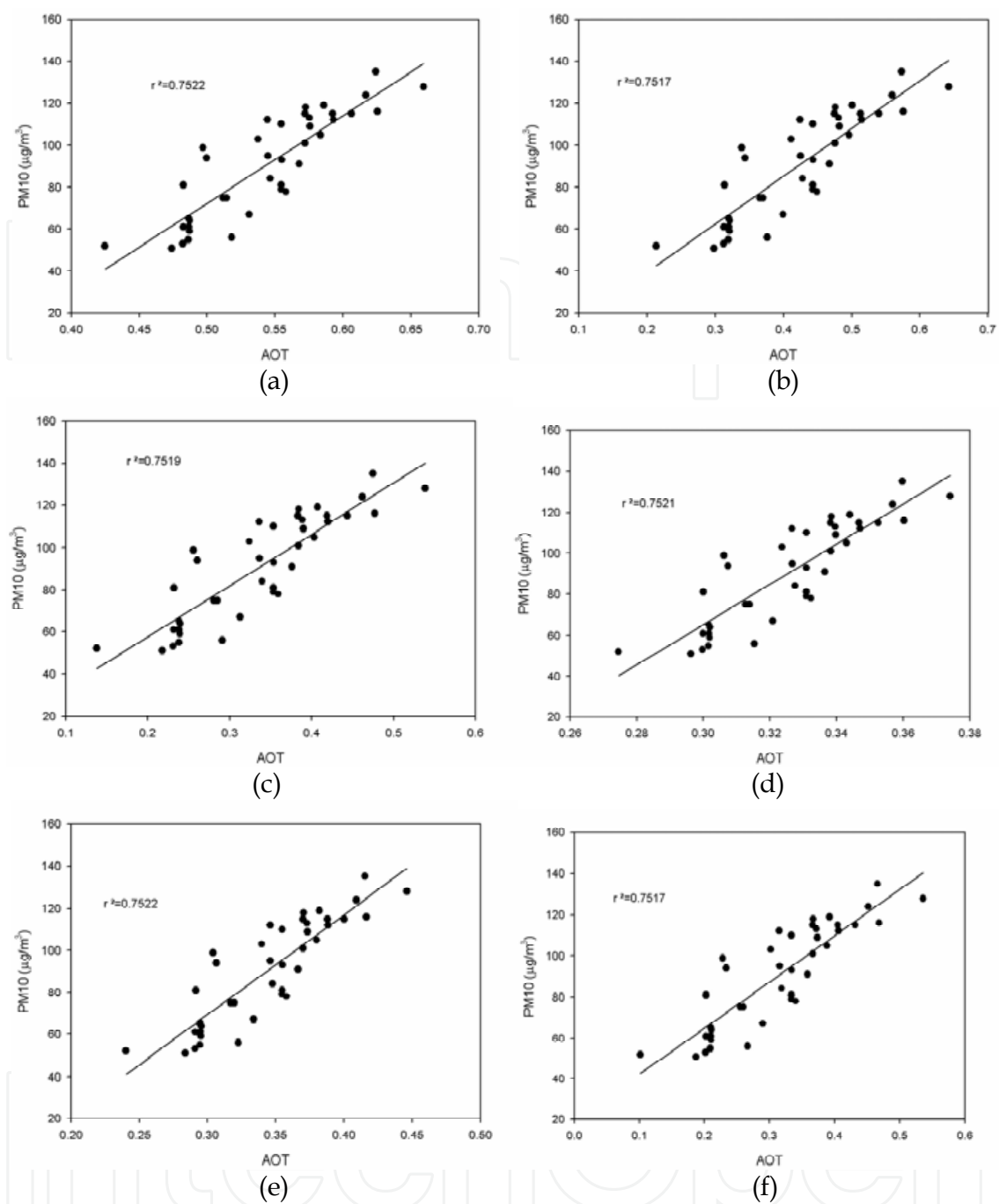


Fig. 4. A linear correlation between AOT and PM10 ( $\mu\text{g}/\text{m}^3$ ) values for (a) 400.5 nm, (b) 500.5 nm, (c) 600.5 nm, (d) 700 nm, (e) 800 nm and (f) 900 nm

## 6. Conclusion

AOT retrieval was produced by the handheld spectroradiometer from the atmospheric transmittance measurements. The results showed that there was a good agreement between AOT and PM10. The spectroradiometer retrieved AOT data had a good positive correlation with the PM10 concentration. This indicates that air quality can be retrieved from the spectroradiometer transmittance measurements. The interpolated AOT map can be used to discern air quality categories such as good, moderate and unhealthy to a relatively high



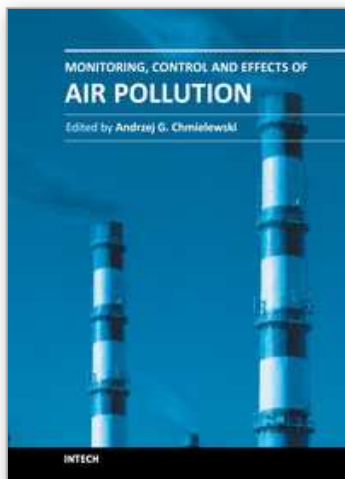
degree of confidence. A linear relationship between PM<sub>10</sub> and AOT was found by this study. Findings can be used to analyze the air pollution levels over Penang Island.

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## **Monitoring, Control and Effects of Air Pollution**

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The book addresses the subjects related to the selected aspects of pollutants emission, monitoring and their effects. The most of recent publications concentrated on the review of the pollutants emissions from industry, especially power sector. In this one emissions from opencast mining and transport are addressed as well. Beside of SO<sub>x</sub> and NO<sub>x</sub> emissions, small particles and other pollutants (e.g. VOC, ammonia) have adverse effect on environment and human being. The natural emissions (e.g. from volcanoes) has contribution to the pollutants concentration and atmospheric chemistry governs speciation of pollutants, as in the case of secondary acidification. The methods of ambient air pollution monitoring based on modern instrumentation allow the verification of dispersion models and balancing of mass emissions. The comfort of everyday human's activity is influenced by indoor and public transport vehicles interior air contamination, which is effected even by the professional appliances operation. The outdoor pollution leads to cultural heritage objects deterioration, the mechanism are studied and the methods of rehabilitation developed. However to prevent emissions the new technologies are being developed, the new class of these technologies are plasma processes, which are briefly reviewed at the final part of the book.

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