REMOTE SENSING OF PM10 FROM LANDSAT TM IMAGERY

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ABSTRACT

Air pollution concentration has been estimated over Penang Island from Landsat TM 7. In-situ measurements of the corresponding air pollution parameter (particulate matter less than 10 micron, PM10) were carried out simultaneously with the acquisition of the satellite imagery. Three algorithms were introduced in the present study for the retrieval of PM10 for air pollution mapping and their accuracies were noted. The objective of this study was to test the feasibility of the proposed technique for retrieving air quality values by using the high spatial resolution Landsat TM7 imagery. Semi-empirical relationship has been used for PM10 mapping all over Penang Island. We used thermal infrared and visible wavelengths bands in this study. This study indicated that the satellite scene produced useful information for air pollution mapping.

1.0 INTRODUCTION

Daily remote sensing of aerosol from satellite over the land and ocean is essential to obtain the global aerosol budget to estimate the contribution of anthropogenic emission to the aerosol budget and to the aerosol radiative forcing of climate. Because of the short lifetime of aerosol particles and the corresponding strong spatial variations in the aerosol concentration, ground-based stations cannot assess trends in the global aerosol budget (Kaufman, et. al., 1997). Particular matter (PM), or aerosol, is the general term that was used for a mixture of the solid particles and the liquid droplets were found in the atmosphere (Wang and Christopher, 2003). The large plumes of dust especially from the industrial areas often affect the Penang atmosphere.

Several studies have shown the possible relationships between satellite data and air pollution [Weber, et al., (2001), Ung, et al, (2001a) and Ung, et al., (2001b)]. Other researchers used satellite data for such environment atmospheric studies such as NOAA-14 AVHRR (Ahmad and Hashim, 1997) and TM Landsat (Ung, et al., 2001b). In fact, air quality can be measured using ground instruments such as air sample. But these instruments are quite expensive and are limited by the number of air pollutant stations in each area. So, they cannot provide a spatial distribution of the air pollutant over a city.

In this study, an algorithm has been developed for retrieval of PM10 over Penang Island. We used reflectance values in the visible bands and the raw digital number (DN) in the thermal infrared band measured by the satellite to derive the PM10. This proposed methodology derived from two assumptions, 1. The pollutants should affect visible and infrared bands. 2. The strong correlation between the measured PM10 and thermal infrared band of Landsat TM. Hence our study attempted to measure the PM10 using the relation with the reflectance in the three visible bands and DN in the thermal infrared band.

2.0 STUDY AREA

The study area is Penang Island, Malaysia within latitudes 5^o 12' N to 5^o 30' N and longitudes 100^o 09' E to 100^o 26' E. The corresponding satellite track for the TM scenes is 128/56. The map of the region is shown in Figure 1. The satellite image was acquired on 5-2-2003. The corresponding PM10 measurements were collected simultaneously during the satellite overpasses.

Figure 1 Study area

3.0 ALGORITHM MODEL

The atmospheric reflectance due to molecule, R_r, is given by (Liu, et al., 1996) as

$$R_r = \frac{\tau_r P_r(\theta)}{4\mu_s \mu_v} \quad (1)$$

where

τ_r= aerosol optical thickness (Molecule)

$P_r(\theta)$= Rayleigh scattering phase function

μ_v=Cosine of viewing angle

μ_s=Cosine of solar zenith angle

We assume that the atmospheric reflectance due to particle, R_a, was also linear with the τ_a of a factor, K_0. This assumption was reasonable because Liu, et al., (1996) also found the linear relationship between both aerosol and molecule scattering.

$$R_a = K_0 \tau_p + K_1 \quad (2)$$

Atmospheric reflectance was the sum of particle reflectance and molecule reflectance, R_{atm}, (Vermote, et al., 1997).

$R_{atm}=R_a+R_r$ (3)

where

R_{atm}=atmospheric reflectance

R_p=particle reflectance

R_r=molecule reflectance

$$R_{atm} = \left[K_0 \tau_p + K_1 + \frac{\tau_r P_r(\theta)}{4\mu_s \mu_v} \right] \quad (4)$$

The optical depth was given by Camagni and Sandroni, (1983), as equation (5). From the equation, we rewrite the optical depth for particle and molecule as equation (6)

$$\tau = \sigma \rho s \quad (5)$$

where

τ = optical depth

σ = absorption

s= finite path

$$\tau_r = \sigma_r \rho_r s \quad (6a)$$

$$\tau_p = \sigma_p \rho_p s \quad (6b)$$

Equations (6) are substituted into equation (4). The result was extended to a three-band algorithm as equation (7)

$$A = e_0 + e_1 R_{atm1} + e_2 R_{atm2} + e_3 R_{atm3} \quad (7)$$

where

A = Particle concentration (PM10)

R_{atmi}= Atmopsheric reflectance, i = 0, 1 and 3 are the band number

e_j= algorithm coefficients, j = 0, 1, 2, … are then empirically determined.

Form the equation; we found that PM10 was linearly related to the reflectance for band 1 and band 2. This algorithm was generated based on the linear relationship between τ and reflectance. Retalis et al. also found that the PM10 was linearly related to the τ and the correlation coefficient for linear was better than exponential in their study (overall). This means that reflectance can be considered to be linearly related to the PM10.

We attempted to investigate the contribution from the thermal band. So, the equation (7) can be modified into equation (8) as given below

$$A = e_0 + e_1 R_{atm1} + e_2 R_{atm2} + e_3 R_{atm3} + e_4 DN_6 \quad (8)$$

where DN_6 was the digital number for thermal infrared band

4.0 DATA ANALYSIS AND RESULTS

The images were rectified using the second order polynomial coordinates transformation equation to relate ground control points (GCP) in the map to their equivalent row and column positions in the TM scene. The nearest neighbour method was used to resample the TM scenes. In this study, we used three methods for PM10 mapping. First method, raw digital number (DN) was used as independent variables for algorithm analysis. Second method, we computed the atmospheric reflectance by subtracted the surface reflectance from the total image recorded reflectance. The surface reflectance values for visible bands (TM1, TM2 and TM3) were retrieved by using the established relationship with the mid-infrared band (TM7) [Liang, et al., (1997) and Wen, et al., (1999)]. We assumed the surface reflectance of several selected targets did not change with time in this study. So, we measured the surface reflectance at these selected locations using a handheld spectroradiometer and we obtained the correlations as given below

$$\rho(TM1) = \rho(TM7)/4.26$$
$$\rho(TM2) = \rho(TM7)/1.94$$
$$\rho(TM3) = \rho(TM7)/2.11 \qquad (9)$$

Third method, we combined the atmospheric reflectance in the visible and raw DNs of the thermal infrared band for algorithm regression analysis. Finally, their accuracies were compared based on the correlation coefficient, R, and root-mean-square error, RMS, values. The results of the three methods are show in Table 1.

A map of the air quality parameter was then generated using the coefficients obtained from the regression analysis of our proposed algorithm (using a combination of the thermal infrared and visible data). Water area was masked out using threshold value of band 4 data. Figure 2 shows the generated map.

Table 1. Regression results using different methods of algorithms for PM10

	R	RMS ((μg/m$^{3)}$
$A = e_0 + DN_T$	0.9089	6.6060
$A = e_0 + e_1 R_{atm1} + e_2 R_{atm2} + e_3 R_{atm3}$	0.8650	9.4055
$A = e_0 + e_1 R_{atm1} + e_2 R_{atm2} + e_3 R_{atm3} + e_4 DN_6$	0.9344	7.4628

Note: DN_T, R_{atm1}, R_{atm2} and R_{atm3} are the digital numbers for thermal infrared, atmospheric reflectance values for red band, green band and blue band respectively

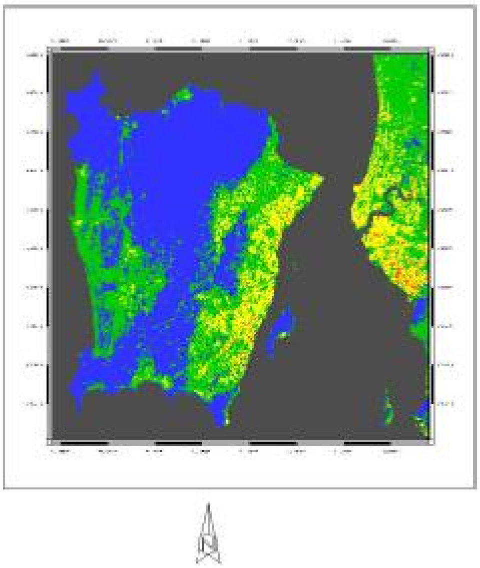

Figure 2 Map of PM10 around Penang Island, Malaysia (Blue < 40 $\mu g/m^3$, Green = (40-80) $\mu g/m^3$, Yellow = (80-120)$\mu g/m^3$, Orange = (120-160) $\mu g/m^3$, red = (>160) $\mu g/m^3$ and Black = Water and cloud area)

5.0 CONCLUSION

Evaluation of existing Landsat TM capabilities indicates that air pollution can be mapped using satellite data to provide a bigger area of coverage. Of course, the realization of these visions for the future of air pollution research is dependent on more than improved surface reflectance retrieval methods. It will also depend on more accurate and better measurements of the in situ data needed for calibration of the algorithm. Further investigation should be carried out to verify the accuracy of our algorithm that employs visible and thermal infrared band data of Landsat TM for calibration.

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