REMOTE SENSING TECHNIQUE FOR MONITORING OF URBAN AIR QUALITY

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Abstract: Disturbance of air quality standard is a long remaining problem in Malaysia. Industrialization, vehicles increasing, globalization and urban growth are the main problem that contributing to the environment issues. The problems of air pollution in this country has risen concerned and becoming one of the most important issues when those issues involve public health and safety of the population. Air pollution depends on various factors including weather conditions, topography and local situation. Sufficient studies are required not only for healing the illness but also to provide evidence of the main contributing factors of the air pollution. This paper presents the method of extracting air pollutants from remotely sensed imagery and maps them. Satellite images were manipulated in the digital image processing system in order to derive the aerosol optical thickness, indicating how much radiance is disturbed on its way through the atmosphere and at-temperature, calculated from the visible, near infrared and thermal infrared bands of Landsat 7-ETM. Air pollution concentration was mapped via a relation between ground station data and aerosol optical thickness and at-satellite temperature. Aerosol optical thickness in green and red bands and temperature show significant relation with particular matter, black particles and carbon monoxide respectively. The result and spatial variability of these pollutants can be mapped with remote sensing.

INTRODUCTION

Air pollution is the most common phenomena that exist in human life. Nowadays, there are various issues involving the environment such as water pollution, open burning, throwing sewage and rubbish everywhere, greenhouse effects, acid rain, haze, thinning of ozone layer ang lots more factors that can contribute to the negative aspect in the environment itself and also the urban ecosystem. Seasonal changes and chemical reactions contribute to the concentrated of the polluted air. Many factors parameter causes air pollution, including weather conditions, humidity, and topography, relief of the area and local conditions such as ventilation in traffic corridors and presence of the buildings.

Pollution defines changes in physical properties, thermal, chemical or biology directly or indirect environment parts of earth. This can happen through emission, contribution of putting the dangerous objects to the earth whether it is toxic or polluted properties for illegal activities. Air pollution consequently shows high spatial variability, even at short distances. The effects of air pollution to the public especially the sensitive group of people, such as the elders, children and people with asthmatic and respiratory health problems. The widely common elements exposure to the air pollutants has adverse effects upon respiratory diseases such as asthma. Asthma is one common chronic disease in the world and has increased id locally over past two decades.

Air pollution happens when the concentration of polluting gases, substances and particles in the atmosphere exceeds the specified safety levels. Among the most harmful and poisonous substances are identified as ; Sulphur Dioxide (SO2), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Ozone (O3) and Particulate Matter or less than 10 µm (PM_{10}).

Conventional methods of mapping and monitoring air pollution were performed using data collected from air monitoring network and statistical functions (Afroz et. Al., 2003). Remote sensing approach applied in the air pollution studies has been a new revolution in environmental management. Satellite imageries were manipulated through various digital image processing techniques in order to extract atmospheric information that could be used for monitoring and managing iar pollution problems. Modeling, interpolation and mapping of air pollution not only provided a clear view of the problem but also finding the solution for the issues.

The aerosol optical thickness (AOT) parameter can be used to characterize and quantify atmospheric air pollution levels from remotely sensed images. Using satellites, the gasses values can be obtained faster and can reduce diseases if the safety precautions are taken as soon as possible.

Some air pollution research uses aerosol optical thickness to detect air pollution. Aerosols and gasses in the atmosphere disturb the radiance reaching to the sensor by scattering and absorption. This reduces the contrast of the remotely sensed images (Sifakis et. Al., 1998). It can be calculated from multi-spectral images with higher resolution, such as Landsat ETM+.

Aerosol Optical Thickness (AOT) referred to the total volume of aerosol suspended in the atmosphere and contains all types of atmospheric particles, water vapor, dust. Ashes from volcanic eruption, smokes from forest fire and open burning and many more. That means that that the aerosols can be in both forms of liquid and solid particles which can be sorted according to their sizes. Sifakis et. Al (1998) defined AOT as integral from the ground to satellite (z) with coefficient due to scattering by aerosols K_{sat} at a given wavelength (λ) and its magnitude is directly connected to the concentration of optically effective particles as given by formulas below,

$$AOT\ (z, \lambda) = \square K_{scat}\ (Z', \lambda')dz'$$

This study focuses on the determine concentration of parameter carbon monoxide, particulate matter (PM10) and black particle (BP) for Johor Bahru area. Besides that, this study will test the accuracy for remote sensing technique which measures the air pollution rather than the conventional methods. The basic method is a radiometric comparison of a satellite image recorded under polluted conditions, with a reference image acquired under less polluted condition. Ground data were used to select a less polluted reference image. In remote sensing , different algorithms are used to estimate aerosol optical thickness, depending on the sensor and the spectral band (Sifakis and Deshamps, 1992; Sifakis et. Al., 1998; Retalis et. Al., 1999; Wald and Baleynaud, 1999; Ung et al., 2001). The relation between ground observations and estimates of aerosol optical thickness is described with linear regression providing the spatial distribution of air pollution.

STUDY AREA

The study area of Johor Bahru is located at the southern part of Malaysia. Johor Bahru is the capital city of Johor. Johor Bahru also is the state which is the nearest to Singapore. It receives more than 60% of country's 16 million tourists by its bridges and road links to Singapore. It is one of the largest cities in Malaysia. The city is an important industrial, tourism and commercial hub for southern Malaysia and is part of one of Southeast Asia's most populous urban areas. The population growth rate of Johor Bahru is also among the highest in Malaysia. Johor Bahru also has a highly developed industrial base which has made the city one of the biggest industrial centers of the country. The city of Johor Bahru is located at 1º29'N, 103º44'E. the city council administers the highly developed southern central coast of the metropolitan area, with a total area of 185 km^2.

MATERIALS AND METHODOLOGICAL APPROACH

The optical thickness of aerosol scattering and the absorption, in visible and thermal parts of the spectrum was evaluated using a combination of two independent methods, namely the apparent reflectance and blurring effects.

Landsat 7 ETM images were classified into two different sets of data. The first set which consist of polluted images are mainly covered with thin yellow-brownish clouds or hazy, while the second set served as reference images are almost free from cloud covers and haze. The images were processed and corrected for geometric and radiometric distortion and were geocoded according to the Malaysian geo-reference system. In order to derive the AOT information, the digital number (DN) of the images should be subsequently processed to obtain atmospherically corrected reflectance. In these computations, ancillary data available in the image file header is essential.

Since the method is based on comparison, two remote sensing images in the visible and thermal part of the spectrum were required, one on a clear (less polluted) day and one on a polluted day. The AOT values were calculated using techniques introduced by Sifakis and Paronis (1998), where radiometric values of cleared and polluted images are compared and evaluated. Based on the ground data, Landsat ETM+ image on January 28th, 2005 was selected as the image of a polluted day and that of April 2nd, 2002 as the image of a (relatively) clear day. The delineation and elimination of can be carried out using different types of image processing algorithms, i.e., conditional technique. The correct way is when highest AOT val8ues were found in areas of most pollutant emission. Major industrial, chemical sites and main town areas where the emissions of vehicular gases are normally uncontrollable are among the area that would present higher AOT. Changing DN values to at satellite radiance then to at satellite reflectance is to eliminate the geometrical illumination effects. While all the values of AOT are being gathered by using remotely sensed images, ground data are observed at Continuos Air Monitoring Station (QAMS) in Pasir Gudang, Johor Bahru and Senai.

The equation to convert DN image into at-satellite reflectance image is adapted from Landsat 7 Data User's Handbook (2006) and Lillesand et al., (2004) as below.

$$REF = \frac{(PI \times (L_{sat} - L_{haze}))}{TAU_v \times (EO \times \cos(TZ) \times TAU_z + E_{down})}$$

Where,

REF = spectral reflectance of the surface,

L_{sat} = wavelength for Landsat ETM and TM,

L_{haze} = upwelling atmospheric radiance scattered in the direction of and at the sensor,

TAU_v = atmospheric transmittance along the path from ground surface to sensor,

TAU_z = atmospheric transmittance along the path from the sun to ground surface,

EO = the earth-sun distance term (d*d) embedded in Astronomical units,

TZ = angle of incident of the direct solar flux or solar zenith angle,

E_{down} = downwelling spectral irradiance at the surface due to scattered solar flux in the atmosphere ($Wm^{-2}\mu m^{-1}$).

However, the model used in this study is a simplified model also known as "Apparent reflectance model" because of limited parameters availability (Chavez, 1996). Parameters of upwelling, downwelling and atmospheric transmittance are not available in this study. Several assumptions have to be made to initiate the process of calculating AOT. Model introduce by Moran et al (1992) need to be simplified by assuming that some parameters regarding atmospheric effects which are not available. The following assumptions made by Chavez (196) are applied in Moran's equation above,

TAU_z = 1.0 (ignores atmospheric transmittance along the sun to ground surface)

TAU_v = 1.0 (ignores atmospheric transmittance along the ground surface to sensor)

E_{down} = 0.0 (ignores downwelling spectral radiance at the surface)

L_{haze} = 0.0 (ignores scattering due to path radiance)

This model is applied in this study after considering that it is appropriate with all the parameters available in ancillary data of the satellite image used.

$$Apparent\ Reflectance = \frac{\pi \times L_\lambda \times d^2}{EO_\lambda \times \cos(\theta)} (unitless)$$

Where:

L_λ = radiance value at satellite (W/(m^2*ster*μm))

EO_λ = extraterrestrial solar zenith angle (degree)

d = earth-sun distance (unit astronomy)

θ = angle which is available in the header file of the image

Calculations for aerosol optical thickness (AOT) using blurring effects and SMA (satellite mapping of aerosols) code

Satellite derived AOT is relevant to aerosol tracking because AOT is sensitive to number of emissions and pollutant concentrations and AOT is not limited to ground levels aerosols concentration.

Applying the ratio of the "reference" image pixel values to the "pollution" image pixel values combines the "pollution" and the "reference" images. After considering the ffects of atmoshperic scatter, the AOT equation can be shown below,

$$\tau = \cos\theta_v \cdot \ln\left[\frac{\sigma\,(\rho * reference)}{\sigma\,(\rho * pollution)}\right]$$

Where,
θ_v = viewing angle for both Landsat Images 2002 and 2005 respectively, 15.4˚
σ = standard deviation for reference image and polluted image where reference image 2002 is 0.053 and 2005(polluted) is 0.040
ρ = apparent reflectance for both Landsat Images(Calculate from the image)

Calculation for temperature using Landsat ETM and TM

Temperature determination from the satellite data have been widely used by researchers especially in manipulating using Landsat-7 ETM. Temperature derived in this study is referred to equation by Wukelie et al. (1989).

Temperature equation can be derived as below,

$$TR = K_2 / \ln(K_1/L_c + 1)$$

Where,
TR = earth surface
K_1 = calibration equation (60.776 m W cm^{-2} sr^{-1} μm^{-1})
K_2 = calibration equation (1260.56 K)
L_c = corrected radiance value for each pixels

RESULTS
Regression analysis and mapping

Using linear regression, we established relations between processed output image AOT and AT and ground data considering each measured pollutant separately as dependant variable and AOT and AT as independant variables. The relations between processed images which are Aerosol Optical Thickness (AOT) and temperature image (AT) for year 2002 and 2005 with the ground data can be obtained.

Pixels with clouds and water were excluded from analysis, because correct results are only obtained on land area (Sifakis and Deschamps 1992; Sifakis et al., 1998). Best relations were found for PM 10, BP and CO. Daily averages of PM 10 and daily averages of BP are significantly corrected with AOT (bands 2) and AOT (band 3) respectively. Daily averages of CO show significant relation with AT of band 6. This resulted in the following equations for mapping.

CO = 0.085 (AT) – 1.102
PM 10 = 168.3 (AOT2) + 7.551
Black Particles = 2.573 (AOT3) + 53.66

	Minimum	Maximum
Black Particles	56	60.74
PM 10	52.1	57
CO	1.31	1.74

Table 1: Concentration range of BP, PM10 and CO over the study area. ($\mu g/m^3$)

DISCUSSION

From the calculation and model maker from ERDAS IMAGINGE 8.7, the output of the temperature shows the range of surface temperature for the year 2002 is between 24.5 to 33.0 degrees celcius and for the year 2005 the range is between 25.0 to 32.5 degree celcius. This can be seen that the vegetation area have the lowest temperature for both images. The red color shows the hottest spot for the area which are industrial area and urban. For the results, it show the temperature for April 2002 is lower than January 2005.

For the concentration of these three gasses, PM10 is significantly correlated with AOT2, BP with AOT3 and CO temperature. Particle sizes of aerosols generated by pollutants may be a reason for the fact that different components have relations with AOT or AT of different bands. Another reason may be their chemical and physical properties.

In figure 2, CO shows high concentration in the southern and eastern pasrts of the study area. This can be shown by the red color which contains the highest concentration for carbon monoxide which is at the range 1.31 – 1.74 $\mu g/m^3$. This high concentration area consists of 3 districts which are area Johor Bahru itself, Tebrau and Plentong which is near Pasir Gudang. This is due to road traffic, industrial area which can be found more in Pasir Gudang and office area.

For figure 3, PM10 shows high concentration in the middle part of the image. This consists four districts which are Pulai, Johor bahru city, Plentong and Tebrau. The highest concentration for PM10 from the calculation is between ranges 52.1 – 57 $\mu g/m^3$ shows in red color.

Correlation is the process that determines the strength and weak relation between parameter and axis. In this study, paired t-test have been chosen to see the relations between output values from the images and field data obtained by three different station whichare pasir Gudang, Larkin and Johor bahru. The paired t-test is being used in this study to eliminate the high coefficient to get better comparison between both of the data.

These data have been used to compare the accuracy between these gasses and their ground data. From the output results, we can see that correlation for particulate matter (PM10) is quite high which shows 0.63 where this value is more than 0.5 and nearly 1. So we can say that particulate matter correlates and have strong relationship between field and image is 0.817 which is higher than particulate matter. For black particles the correlation between field and image shows 0.655 which this is the lowest among the two other gasses. Overall, these three gases have moderate and strong relationship between ground and field data. The t-test result for each of these gasses can be shown as in the table below,

Variables	Degree of freedom	T statistic table	T from result
PM10	24	1.711	0.385
CO	25	1.708	1.368
BP	22	1.717	1.142

Table 2: t-test values

There are 25 data values for PM10, 26 for carbon monoxide and 23 values for black particles in Pasir Gudang, Larkin and Johor Bahru area. To validate that remote sensing techniques can be used in determining concentration air pollutants, the t-test have been used to verify these data sets. From table 2 the test from the output results. Based on t-test result from table 2 above, these three gasses have values which are lower than the t from statistical table. This shows that this study is significant and valid to be used.

CONCLUSION

Daily averages of CO and PM10 and daily averages of BP shows a good relation with their estimates calculated from images via AT (band 6), AOT (band 2) and AOT (band 3) respectively. At somelocations, however, values from ground measurement are much lower than the estimates from images. In such situation pollution can be detected by remotely sensed images but not by ground level data. If the area has high deposition rate, the pollutant collected at ground level shows a higher value than the image outputs. Geo-referencing and removing water bodies and clour cover are important. For a regression analysis between ground data and aerosol optical thickness from images, it gives the best result. This study shows how remote sensing can be used to map the spatial variability of urban air pollution by CO, PM10 and BP. The greater spatial detail provided can be used to improve estimates based on interpolation between ground observations and dispersion models.

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