THE AEROSOL LOADING FOR INLAND AND CLOSE-SHORE CITY DERIVES FROM URBAN ATMOSPHERIC MODEL

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Abstract

Visibility degradation has become an environmental topic of community concern in most urban areas because of low visibility range that will lead to the deterioration of air quality. Atmospheric aerosol plays an important indicator of visibility distance range because it will influence the objects that can be seen. Microclimate can be defined as the climate of a small area such as part of a city. Inland city is the city located at interior of a country or region while close-shore city is the city that is surrounded by the sea or located near the sea. Both areas have different microclimate types.The objective of this study is to investigate the relationship of visibility range with atmospheric aerosol that can possibly be used as an indicator of air quality between the inland and close-shore city. The study used atmospheric model for urban aerosol algorithm in ATCOR2 PCI Geomatica to analyse the distribution of aerosols in terms of percent (%) reflectance. Landsat 5 Thematic Mapper images in Penang Island and Kuala Lumpur for the year 1993, 1999 and 2005 have been used to determine the aerosol loading. The atmospheric aerosol loading from the image was retrieved by different visibilities range at the distance of 10 km up to 50 km which are later converted into (%) reflectance. The mean reflectance values of a 3x3 pixel window were derived over urban features for both areas. The pattern of aerosol loading increased when visibility range is in between 10 to 20 km and decreased when visibility range is more than 30 km for both areas. In year 1993, the maximum aerosol loading was 9.7% in Kuala Lumpur and 15.1% in Penang Island. In year 1999, the highest aerosol loading was recorded at 11.3% in Kuala Lumpur and in Penang Island, the reading was 17.9%. The maximum aerosol loading showed in year 2005 was 10.1% in Kuala Lumpur and 20.0% in Penang Island. From the results, it shows that the aerosol loading for different atmospheric climates can be estimated using urban atmospheric model. The distance of the range of visibility can be used as an important parameter to determine the aerosol loading.

Keywords: *Aerosols, reflectance, visibility, microclimate and imaging data*

1. Introduction

The study of atmospheric aerosol is very important in order to understand the earth's solar radiation budget, water cycle balance, and climate change dynamics (Ichoku *et al*., 2004). Aerosols have a direct radiative forcing because they are scattered and able to absorbed solar and infrared radiation in the atmosphere with different wavelength (Stefan *et al*., 2006) which warms up the ambient and reduces the solar radiance reaching the earth (Cheng *et al*., 2006). Atmospheric aerosol manipulates many atmospheric processes including cloud formation, visibility variation and solar radiation transfer. Both gaseous and particulate components of atmospheric aerosols contributed to the deterioration of air quality (Fang and Chang, 2010).

Atmospheric aerosols are generally considered as particles ranging from the size of a large molecule, approximately 1 nanometer (nm), to coarse supermicron sea-salt and soil dust particles that may be bigger than 10 micrometers (µm) in diameter (Virkkula *et al*., 2009). Atmospheric aerosols contained nonvolatile species such as metals, salt, soot and crustal oxides. It also has semivolatile compounds such as nitrates, sulfates and particulate matter (McMurry, 2000). It was also known as primary and secondary aerosols. Primary aerosols are emitted directly into the atmosphere from sources such as sea spray, wind-blown soil and dust, coal burning and road traffic while, the secondary aerosols are formed in the atmosphere by the oxidation of nitrogen oxides into nitrate particles and sulfur oxide into sulfate particles (Cheng *et al*., 2003).

Current study by Richter (2007) stated that the urban aerosol type are regular particles such as sulfate aerosols resulting from combustion and industrial activities while the maritime aerosol type is from sea-salt, dust-like and organic particles. The rural aerosol type is composed mostly of dust-like and organic particles which originate from atmosphere in areas that are not strongly influenced by urban or industrial centers. The types of aerosol usually inferred its geographic location. Iorga and Stefan (2007) in their studies mentioned that the rural aerosol is a mixture of ammonium sulfate and mineral dust; and marine aerosol is from pure ammonium sulfate.

Visibility degradation has become an environmental topic of community concern in most urban areas because of low visibility range will portray the deterioration of air quality (Bäumer *et al*., 2008). Reduction in visibility occurred when particles, and to a lesser extent gases, would scatter or absorb light which known as light extinction. Visibility reduction was caused by the existence of secondary fine aerosol particles whose production depends on the oxidizing ability of the atmosphere (Aneja *et al*., 2004). Visibility was influenced not only by concentration of air pollutants but can also be related to meteorological variable such as wind speed and atmospheric pressure. Tsai (2005) stated that visibility increased with temperature and wind speed but decreased with atmospheric pressure. Relative humidity also related to visibility degradation especially in coastal area. Formation of sulfates will increase in water droplets under high humidity condition (Cheng and Tsai, 2000).

Visibility can be defined as the maximum distance an object or details of a complex pattern can be visually identified with unaided eyes (Horvath, 1994). Previous studies have demonstrated that the size, chemical composition, and concentration of airborne particles closely influence visibility (Conner *et al*., 1991; Malm and Pitchford, 1997; cited in Yuan *et al*., 2006). Tsai *et al*., (2007) found that the specific content of $PM_{2.5}$ which is sulfate, is one of the significant factors that affected visibility range. This is due to the size and chemical composition of each component particle affects its capability to refract, scatter, and absorb light.

Atmospheric aerosol is related to visibility because it is an important indicator of air quality whereby the increasing of aerosol loading will contribute to the degradation of visibility (Cheng and Tsai, 2000). Past studies at Kaohsiung city in China showed that sulfate in $PM_{2.5}$ was the most sensitive species to visibility variation because, the percentage contributions of visibility degrading to light scattering were 29% for sulfate, 28% for nitrate, 22% for total carbon and 21% for $PM_{2.5}$-remainder (Yuan *et al*, 2006). They concluded that by reducing the composition of sulfate in $PM_{2.5}$ it could effectively increase the visibility in Kaohsiung city.

Therefore, the objective of this study is to investigate the relationship of visibility range with atmospheric aerosol that can possibly be used as an indicator of air quality between inland and close-shore city in Malaysia.

2. Data and Material

2.1 *Data Acquisition*

The satellite images were obtained from the Malaysian Remote Sensing Agency (MRSA) for the year 1993, 1999 and 2005 for both Kuala Lumpur and Penang Island. In this study, the images used are Landsat 5 TM with 30 meter resolution. In this study, level 1A of raw data for the year 1993 and 1999 were used; and year 2005 was level 2A for both sites. Detailed description showed in Table 1 and Table 2 below;

Images Description	Acquisition Year		
	1993	**1999**	**2005**
Sensor Type	Landsat 5 TM	Landsat 5 TM	Landsat 5 TM
Date	26-02-1993	11-02-1999	22-08-2005
File name	127058r_19930226	127058r_19990211	12503_20050822
No. of band	6	6	6
Path/row	127/058	127/058	127/058
Resolution	30m	30m	30m
Cloud cover (%)	1.5	3.4	clear

Table 1: Description of Landsat 5 TM Images for Kuala Lumpur

Images Description	Acquisition Year		
	1993	**1999**	**2005**
Sensor Type	Landsat 5 TM	Landsat 5 TM	Landsat 5 TM
Date	1-02-1993	22-03-1999	02-02-2005
File name	128056r_19930201	128056r_19990322	12546_20050202
No. of band	6	6	6
Path/row	128/056	128/056	128/056
Resolution	30m	30m	30m
Cloud cover (%)	0.1	24.5	clear

Table 2: Description of Landsat 5 TM Images for Penang Island

2.2 ***Study Sites***

Two cities with different types of microclimate have been selected for this study. Kuala Lumpur is chosen as a study area due to its 100 percent level of urbanization (Department of Statistics, 2012). The geographic location of Kuala Lumpur is within latitude 03°09'N and longitude 101°41'E and located at the centre of the country Malaysia. The temperatures ranging between 26.4°C to 29.0°C with relative humidity is high all over the year round (Malaysian Meteorological Department, 2012). In this study, this site will represent the inland city.

The second study area is located in Penang Island; the city is surrounded by the sea and within latitudes 05°25'N and longitudes 101°15'E. Penang Island is the second largest city in Malaysia and it is the most populated island in the entire country with an estimated population of 720,000 (Tan *et al*., 2010). The climate is generally warm throughout the year with temperatures ranging from 23.9°C to 31.1°C. Humidity is generally high all year round. April, May and October are usually the wetter months (Malaysian Meteorological Department, 2012). For that reason, this site has been chosen as a close-shore city.

3. Research Methodology

3.1 ***Image Pre processing***

In this study, the raw images from the year 1993 and 2005 were geo-referenced to a common geocoded coordinate system based on the geocorrected images from the year 1999. Then, it was re-sampled using the nearest neighbor algorithm with a pixel size of 30m by 30m for all bands. The RMSE of rectification was less than 0.4 in this study.

3.2 ***Atmospheric Parameter in ATCOR 2 PCI Geomatica***

This study uses atmospheric model for urban aerosol algorithm in ATCOR2 PCI Geomatica to analyse the distribution of aerosols in terms of percent (%) reflectance. ATCOR2's functioned was calculated correctly for flat areas where applying constant or varying atmosphere accounting for adjacency effect (Othman *et al*., 2010).

Parameter	Value	Source of information
Model of region	Urban	Location of the site
Calibration file	Landsat4_5/tm_standard.cal	Sensor type=Landsat 5 TM Pixel size=30m
Visibility	10km to 50km	Ground observation adjusted by iterative procedure in ATCOR2
Adjacency	1.0	Estimated as default for most cases

Table 3: Summary of parameters used in ATCOR2. The parameter include model of region, calibration, visibility and adjacency value.

This study was based on processing the data using ATCOR2 because; the software consists of visibility layers that would be used to determine the reflectance values. Ground reflectance data retrieved from satellite imagery can be compared to ground measurements, providing an opportunity to verify the results (Richter, 2007).

3.3 *Atmospheric Model for Aerosol Loading Estimation*

In order to estimate the aerosol loading, urban aerosol was chosen to represent the aerosol condition in the atmosphere.

The visibility part was used with different values because this study aims to investigate the relationship of visibility with reflectance of urban aerosol. The visibilities range chosen is 10 km up to 50 km, respectively.

Eleven samples were collected randomly over urban area. The mean reflectance values of a 3x3 pixel window were derived for each sample. The result will provide in scaled surface reflectance which later converted into percent (%) reflectance using scale factor 4.

4. Results and Analysis

4.1 *Aerosol Loading between Inland and Close-shore City*

Table 4 shows the estimation of aerosol loading using visibility range for both Kuala Lumpur as inland city and Penang Island as close-shore city. The measurement of aerosol loading is in unit percent (%) reflectance. From the result, it shows that the decreasing of % reflectance when the visibility range increased for both sites.

Aerosol loading in Penang Island is larger than in Kuala Lumpur. Estimation of aerosol loading has been recorded with maximum values of 15.1% (1993), 17.9% (1999) and 20.0% (2005) compared to Kuala Lumpur. In Kuala Lumpur, the aerosol loading with maximum values were measured which are 9.7% (1993), 11.3% (1999) and 10.1% (2005). From all cases, it shows that the maximum aerosol loading is reached when the visibility range is set at 10km. The minimum values of aerosol loading were recorded in Kuala Lumpur with 8.4% (1993), 9.3% (1999) and 8.5% (2005) while in Penang Island; the minimum values were 11.6% (1993), 13.6% (1999) and 14.3% (2005). The minimum values were estimated at 50km for both sites.

From the result, it shows that year 2005 was recorded as the highest estimated aerosol loading for both sites. In Kuala Lumpur, the aerosol loading that has been recorded were 10.1% (10km), 9.0% (20km), 8.6% (30km), and 8.5% (40 and 50km) while in Penang Island were 20.0% (10km), 15.9% (20km), 15.2% (30km), 14.7% (40km), and 14.3% (50km). The pattern of aerosol loading increased when visibility range in between 10 to 20km and decreased when visibility range is more than 30km for both areas. During the three year period, the amount of aerosol loading estimation for Kuala Lumpur decreased when the visibility range goes up from 10km to 50km. The similar pattern also goes to Penang Island; the farthest of distance range, the lower of aerosol loading was measured.

According to the results that have been recorded, there are possible causes that the aerosol loading in Penang Island was higher than in Kuala Lumpur. The atmospheric factors such as humidity, temperature and wind affected the amount of aerosol loading. In Penang Island, the temperature ranges from 23.9°C to 31.1°C. Humidity is generally high all year round. April, May and October are usually the wetter months (MET, 2011). Also, the geographic location which is located near the close-shore will influence the aerosol loading. Higher temperatures could lead to higher rate of smog formation, and lower wind speeds may tend to keep pollutants concentrated over urban areas (Che-Ani *et al*, 2009).

Visibility range (km)	**Estimation of aerosol loading (% reflectance)**					
	1993		**1999**		**2005**	
	Kuala Lumpur	**Penang Island**	**Kuala Lumpur**	**Penang Island**	**Kuala Lumpur**	**Penang Island**
10	9.7	15.1	11.3	17.9	10.1	20.0
20	8.7	12.6	9.9	15.0	9.0	15.9
30	8.5	12.1	9.6	14.1	8.6	15.2
40	8.5	11.7	9.4	13.8	8.5	14.7
50	8.4	11.6	9.3	13.6	8.5	14.3

Table 4: Estimation of aerosol loading for Kuala Lumpur and Penang Island

4.2 *Correlation between Atmospheric Aerosols and Visibility Range*

Table 5 showed the dependency analysis of correlation (Pearson) of aerosol loading with visibility range for both Kuala Lumpur and Penang Island. The results for both sites showed that the highest significance of correlation is recorded above 0.800. The correlation for Kuala Lumpur were 0.825(1993), 0.873(1999) and 0.860(2005). In Penang Island, the correlation were 0.867(1993), 0.875(1999) and 0.865(2005).

Year	**Correlation (Pearson) between aerosol loading and visibility**	
	Kuala Lumpur	**Penang Island**
1993	0.825	0.867
1999	0.873	0.875
2005	0.860	0.865

Table 5: Correlation (Pearson) for Kuala Lumpur and Penang Island

Basically, urban aerosol type is particles such as sulfate aerosols resulting from combustion and industrial activities (Richter, 2007). However, this study only focuses on general of aerosol type. It is because; there is no attempt to distinguish the aerosol element using the atmospheric model.

5. Conclusions

Aerosol loading in Kuala Lumpur and Penang Island showed significant decreased when the long distance of visibility is used. From this study, a general conclusion has been proposed in which the decreasing of aerosol loading when the visibility increase might be due to human activities and geographic location of the study area. The meteorological factor such as temperature and humidity might be affecting the amount of aerosol loading. Thus, the atmospheric model can be used to estimate the aerosol loading in different microclimate types which is inland and close-shore city using urban aerosol algorithm. In future study, several works need further focus. Firstly, the spatial extractions need to be improved in order to estimate the aerosol loading. Secondly, the impact of the distribution pattern of different land use/cover types in urban areas needs to be further studied. Thirdly, it is important to investigate human activities and other impact factors on decreasing amount of aerosol loading.

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