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Dengan Kerjasama:

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DETERMINING OF PM 10 AQI OVER MALAYSIA USING NOAA-14 AVHRR SATELLITE DATA

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Particulate Matter sizing less than 10 micrometers or widely known as PM 10 is one of the major constituents of thick haze phenomenon, which occurred in Malaysia during September 1997. In this study, seven scenes of NOAA-14 AVHRR satellite data were acquired in order to determine and map PM 10 over Malaysia. Five location of air pollution station were chosen where PM10 was measured. Band 1 (wavelength of 0.58-0.68 micrometers) of NOAA-14 AVHRR satellite data were converted from digital numbers to reflectance prior deriving PM 10 information from the imagery. Cloud separation was then carried out by integrating both visual and thresholding technique. Relationship between the satellite reflectance and the corresponding PM 10 AQI (Air Quality Index) at the stations was established using linear regression model. The model was then used to map the concentration of PM10 over Malaysia. The result indicates that remote sensing technique using bands 1 of NOAA-14 AVHRR data was capable to determine and map PM 10 concentration quantitatively. Finally, accuracy was assessed using RMSE technique.

Key Words: PM 10, NOAA-14 AVHRR, AQI

1. Introduction

Haze can be defined as partially opaque condition of the atmosphere caused by very tiny suspended solid or liquid particles in the air [Morris(1975)]. Haze originating from open burning or forest fire contains large amount of particulate matter (e.g., organic matter, graphitic carbon). This particulate matter is hazardous to health, especially associated with lung and eye deceases. Besides that, it is capable of increasing the atmospheric greenhouse effects and affecting the troposphere chemistry.

Conventionally, PM 10 can be measured from ground instruments such as air sampler, sun photometer and optical particle counter, however these instruments is impractical if measurement are to be made over relatively large areas or for continuous monitoring.

The haze episode that occurred during mid-May to November 1997 is considered the worst since 1980 (five similar haze episodes had occurred in April 1983, August 1990, June 1991, October 1991 and August 1994). On 19th September 1997 Malaysian government had declared that Kuching (capital of Sarawak) was in the state of emergency when the PM10 API (Air Pollution Index) exceeded 650 (hazardous level). By 23rd September 1997 the condition worsened as Kuching’s PM10 API reached 839, the highest ever been recorded by the country.

Meteorologist had revealed that it was due to the injection of suspended ash particles from large-scale forest fire in Sumatra and Kalimantan. In addition, the occurrence of shallow localized haze in big cities (e.g., Kuala Lumpur, Kelang, Johor Bahru) caused mainly by vehicle and industrial emissions which were stimulated by the South West Monsoon Season which acted as the minor contributor that made the condition worse. Such phenomenon has created awareness, pertaining to haze early warning system so that precaution measures can be disseminated to public effectively.

This paper reports results of a study to determine PM 10 from NOAA-14 AVHRR satellite data. Their concentration and spatial distribution will be quantified based on updated measurement system, AQI. This current study is an extension of previous work by Ahmad and Hashim [1997; 2000; 2002], and Mazlan et al [2004] that produced models to quantify haze in API.
2. Materials

This study involved the usage of three types of data namely: ground-truth data, satellite data and ancillary data.

2.1. Ground-truth data

Conventional measurements of haze were complementarily used throughout performing data processing for extraction of PM 10 information. PM 10 measurements in micrograms per meter cube (\(\mu g/m^3\)) from 1st to 30th September 1997 were carried out by ASMA (Alam Sekitar Malaysia Sdn. Bhd.) to represent the actual haze intensity over the study area. For the purpose of this study, the measurement was later converted to AQI.

Table 1. Air Quality Index (AQI) for Particulate Matter up to 10 micrometers in diameter (PM 10)

<table>
<thead>
<tr>
<th>Index Values*</th>
<th>Levels of Health Concern</th>
<th>Cautionsary Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 50</td>
<td>Good</td>
<td>None</td>
</tr>
<tr>
<td>51 - 100</td>
<td>Moderate</td>
<td>None</td>
</tr>
<tr>
<td>101 - 150</td>
<td>Unhealthy for Sensitive Groups</td>
<td>People with Respiratory disease, such as asthma, should limit outdoor exertion.</td>
</tr>
<tr>
<td>151 - 200</td>
<td>Unhealthy</td>
<td>People with respiratory disease, such as asthma, should avoid outdoor exertion; everyone else, especially the elderly and children, should limit prolonged outdoor exertion.</td>
</tr>
<tr>
<td>201 - 300</td>
<td>Very Unhealthy</td>
<td>People with respiratory disease, such as asthma, should avoid any outdoor activity; everyone else, especially the elderly and children, should limit outdoor exertion.</td>
</tr>
<tr>
<td>301 – 500</td>
<td>Hazardous</td>
<td>Everyone should avoid any outdoor exertion; people with respiratory disease, such as asthma, should remain indoors.</td>
</tr>
</tbody>
</table>

*An AQI of 100 for PM10 corresponds to a PM10 level of 150 micrograms per cubic meter (averaged over 24 hours).
2.2. Satellite data

Seven sets of NOAA-14 AVHRR data dated 22, 23, 25, 2, 28, 29 and 30 September 1997 acquired from SEAFDEC (Southeast Asia Fishery Development Centre) receiving station were used. NOAA-14 AVHRR was suitable for haze study as it offers high spectral and temporal resolution with a minimum cost. Some useful characteristics of NOAA-14 AVHRR satellite are shown in Table 2.

Table 2. NOAA-14 AVHRR sensor and spectral characteristics

<table>
<thead>
<tr>
<th>Channel No</th>
<th>Wavelength</th>
<th>Typical use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.58 - 0.68</td>
<td>Daytime cloud and surface mapping</td>
</tr>
<tr>
<td>2</td>
<td>0.725 - 1.00</td>
<td>Land-water boundaries</td>
</tr>
<tr>
<td>3</td>
<td>3.55 - 3.93</td>
<td>Night cloud mapping, sea surface temperature</td>
</tr>
<tr>
<td>3A</td>
<td>N/A</td>
<td>Snow and ice detection</td>
</tr>
<tr>
<td>3B</td>
<td>N/A</td>
<td>Night cloud mapping, sea surface temperature</td>
</tr>
<tr>
<td>4</td>
<td>10.30 - 11.30</td>
<td>Night cloud mapping, sea surface temperature</td>
</tr>
<tr>
<td>5</td>
<td>11.50 - 12.50</td>
<td>Sea surface temperature</td>
</tr>
</tbody>
</table>

(Source: Kidwell et al., 1995)

2.3. Ancillary data

Meteorological information over study area, including visibility (Figure 2), air temperature, pressure, relative humidity, wind, etc were obtained from MMS (Malaysian Meteorological Service).

Fig. 2. Reducing visibility of Petronas Twin Towers resulting from the appearance of haze
3. Method

Three modules incorporated in this study are (1) Derivation of haze model, (2) Regression analysis, and (3) Accuracy Assessment.

3.1. Derivation of haze model

Prior to further data processing, post launch calibration of visible Band 1 NOAA-14 AVHRR was earlier implemented in order to compensate data degradation due to extreme temperature change before and after launching of AVHRR sensor to space (Rao et al., 1996). Clouds and haze were successfully differentiated using thresholding technique (Baum et al., 1997). This to ensure both was not being misinterpreted between each other. Model used in this study is based on Siegenthaler and Baumgartner (1996), which make use of skylight to indicate the existence of haze. Skylight is an indirect radiation, which occurs when radiation from the sun being scattered by elements within the haze layer. It is not a direct radiation, which is dominated by pixels on the earth surface. Figure 3 shows electromagnetic radiation path propagating from the sun towards the NOAA-14 AVHRR satellite penetrating through a haze layer. Path number 1, 3 and 4 are skylight caused by direct radiation, whereas path 2 is indirect radiation.

![Diagram](image)

Fig. 3. Model used in this study is based on the skylight parameter (Source: Modified after Siegenthaler and Baumgartner, 1996)

This model can be described by:

\[ \sigma - R = L - V \]  

(1)

where, \( \sigma \): reflectance recorded by satellite sensor, 
\( R \): reflectance from known object from earth surface, 
\( L \): skylight, and 
\( V \): lost radiation caused by scattering and absorption.

3.2. Regression analysis

Calibration pixels of NOAA-14 AVHRR data were sampled within a radius of 2.5 km from each of the air pollution stations. The relationship between PM 10 AQI and satellite-recorded reflectance of band 1 AVHRR, were analysed using linear regression.

3.3. Accuracy Assessment

In order to verify the accuracy of the regression model, RMSE (Root-mean-squared Error) was implemented to the AQI values obtained by the model.
\[ \text{RMSE} = \sqrt{\frac{1}{n} \sum (\text{AQI}_{\text{calculated}} - \text{AQI}_{\text{measured}})^2} \] (2)

4. Results and Discussion

The scatter plot for PM 10 versus satellite reflectance of band 1 NOAA AVHRR with its linear regression trend is shown in Figure 4 where the coefficient of determination, $R^2$ is 0.5563. The linear regression model can be expressed as:

\[ \text{PM10\_Concentration (AQI)} = (5.174 \times \text{Satellite\_Reflectance}) - 77.877 \] (3)

Fig. 4. PM 10 in AQI versus satellite reflectance in percentage. Linear regression trend is shown in black line.

The RMSE varies accordingly for all the five PM 10 ground stations ranging from 7 to 62 and with the average of 33 (Table 3). It is believed that the relatively high RMSE was due to limited number of air pollution stations used. Future study will consider of using more air pollution stations as well as other value-added ancillary data in order gain better and reliable accuracy.

<table>
<thead>
<tr>
<th>Location</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSE (AQI)</td>
<td>33</td>
<td>35</td>
<td>26</td>
<td>62</td>
<td>7</td>
</tr>
</tbody>
</table>

The spatial distribution of PM 10 can be shown in a colourful map (Figure 5) consisting of regions in green (good), yellow (moderate), orange (unhealthy for sensitive groups), red (unhealthy), purple (very unhealthy) and maroon (hazardous). Cautionary Statements for every region are given in detail in Table 1.

<table>
<thead>
<tr>
<th>Colours</th>
<th>Air Quality Index (AQI) Values</th>
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</tr>
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</tr>
<tr>
<td></td>
<td>201 to 300</td>
<td>Very unhealthy</td>
</tr>
<tr>
<td></td>
<td>251 to 500</td>
<td>Hazardous</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clouds</td>
</tr>
</tbody>
</table>

Fig. 5. PM 10 concentration in AQI for 22nd September 1997. The PM 10 level in most area was good and moderate.
5. Conclusion

The study shows that remote sensing technique is capable of determining PM 10 concentration spatially and continuously with minimum cost and time. These are useful in order to provide haze early warnings, so that both government authorized could take necessary measures effectively party as well as public.

References