SPATIAL MODELLING OF AIRBORNE PARTICULATE MATTER CONCENTRATION BASED ON MODIS DATA IN THE UPPER NORTHERN THAILAND

Chat PHAYUNGWIWATTHANAKOON[a], **Pongthep SUWANWAREE**[b], **Songkot DASANANDA**[c,*]

[a] Ph.D. student, Suranaree University of Technology, Mueang District, Nakhon Ratchasima 30000, Thailand; E-mail: chat.ph@gmail.com

[b] Assistant professor, Suranaree University of Technology, Mueang District, Nakhon Ratchasima 30000, Thailand; Tel: (66-44) 224196; Fax: (66-44) 224633; E-mail: pongthep@sut.ac.th

[c] Assistant professor, Suranaree University of Technology, Mueang District, Nakhon Ratchasima 30000, Thailand; Tel: (66-44) 224379; Fax: (66-44) 224316; E-mail: songkot@sut.ac.th

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Abstract: Main objective of this study is to apply MODIS data Band 3 (Blue) and Band 7 (MIR) for estimating near-ground PM10 aerosol density resulted from the widespread forest fires in the upper-northern Thailand. Results of the study suggest that variation of the observed near-ground PM10 (as measured by the PCD) has moderately strong linear relationship with amount of changes in measured radiances at Band 3 and Band 7 with $R^2 = 0.6551$. This relationship was used to create new index called NDAI (Normalized Differential Aerosol Index) to assist direct determination and mapping of PM10 density from the MODIS image data. The gained PM10 density maps (from variation of MODIS data Band 3 and Band 7) can be used to create air quality map (AQI) for further uses in the monitoring and warning purposes of air pollution caused by the PM10 intensification by responsible agencies.

INTRODUCTION

Airborne particulate matter (PM), or aerosol particle, is one of fundamental pollutants responsible for the creation of critical air pollution found around the world (Fenger, 2009). Typically, they can initiate several severe health problems related to the respiratory system (Beeson, Abbey, and Knutsen, 1998; Langkulsen, Jinsart, Karita and Yano, 2006; Kulkarni and Grigg, 2008). As a consequence, great attention has been paid to get better understanding of the spatial/temporal properties of PM-led pollution characteristics and their impacts in recent years; especially over several megacities (Ichoku, Kaufman, Remer and Levy, 2004).

In the past, the study of PM (or any other atmospheric pollutants) distributing patterns mostly relies on data series gained from air quality monitoring networks or measurement campaigns that entail high implementation and maintenance costs and are rather limited in terms of the spatial coverage. However, such limitations can be minimized through the continuous observation of the near-ground aerosol particles by a wide range of the satellite sensors that can be used as a complement to conventional ground data (e.g. MODIS, MISR and POLDER). Satellite imageries have been proved to provide better assess on the spatial structure of PM-led air pollution and interactions on global, regional, or local dispersion patterns (Kaufman, Tanre and Boucher, 2002).

The severity of aerosol pollution is now well acknowledged but the researches that have applied remote sensing or geographic information system (GIS) technology to the study of this concerned problem in Thailand systematically are still rare (e.g. Kim, Upadhyay, Zhuang, Hao and Murthy, 2006; Chew, Chang, Salinas and Liew, 2007; Kishi, Takeuchi, Sawada, 2008). Moreover, the measurement of PM density at relatively fine-scale (like at 500m resolution) has never been reported before. As a result, most knowledge about the severity and distribution pattern of the aerosol pollution arisen from both referred sources is still depended principally on the sparse ground-base measurements located in the urban areas. As mentioned earlier, this method is inadequate for the monitoring and modeling the situation in fine spatial detail, especially at the provincial or regional scales, which is necessary for the better understanding and managing of the incidence by responsible agencies.

The main objective of this study is to map near-ground PM concentration locating in 8 provinces in upper northern Thailand (due to the biomass burning) (Figure 1) at a relatively fine scale (500m resolution) using MODIS satellite imagery in two visible bands (blue and red) and a MIR band (at 2.1 μm). In this work, a new index called NDAI (Normalized Differential Aerosol Index) is also introduced to quantify amount of the PM density in the near-ground atmosphere.

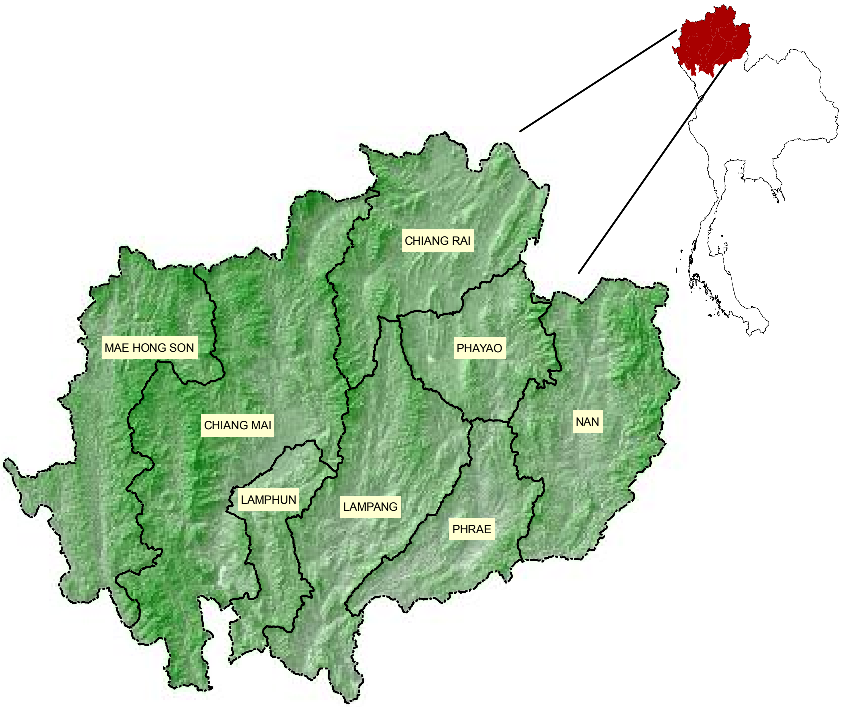

Figure 1: Map of the study area (Upper Northern Thailand).

RESEARCH METHODOLOGY

There are three main steps that were fulfilled in this research:

1. Find proper relationship between the observed near-ground PM10 density and the measured radiance intensities at MODIS sensor's Band 3 (Blue Band) and Band 7 (MIR Band);
2. Generate PM10 density map using NDAI (Normalized Differential Aerosol Index);
3. Generate air quality map (AQI map) from the PM map gained in Step 1.

In Step 1, proper relationship between observed near-ground PM10 density and the measured radiance intensities at MODIS sensor's Band 3 (Blue Band) and Band 7 (MIR Band) was investigated. This relation was assumed to be in a linear form as follows:

$$\Delta PM10 = af[\Delta\, RA(Blue), \Delta RA(MIR)] + b \qquad (1)$$

where a, b are proper constants of the relation and f[Δ RA(Blue), ΔRA(MIR)] is function of changes in the radiance intensity of MODIS's Blue [RA(Blue)] and MIR [RA(MIR)] bands that give rise to the variation in the measured PM10 density (or ΔPM10) on the right-hand-side.

In Step 2, the gained relation in Eq. (1) was used to generate PM10 density map using newly-introduced index NDAI (Normalized Differential Aerosol Index) defined as (a is a proper constant)

$$NDAI = \frac{RA(Blue) - aRF(MIR)}{RA(Blue) + aRF(MIR)} \qquad (2)$$

In Step 3, the air quality index map (AQI) from the PM map gained from Step 1 was made based on the standard formula used by the Pollution Control Department (PCD) as follow

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \qquad (3)$$

where

I = Air Quality Index, C = the pollutant concentration,
C_{low} = the concentration breakpoint that is $\leq C$,
C_{high} = the concentration breakpoint that is $\geq C$,
I_{low} = the index breakpoint corresponding to C_{low},
I_{high} = the index breakpoint corresponding to C_{high}.

All breakpoint data for the PM_{10}-AQI derivation are illustrated in Table 1 and meanings of the AQI at different levels are described in Table 2.

Table 1: Category of breakpoints for computing AQI values of PM_{10}.

C_{low}	C_{high}	I_{low}	I_{high}
0	40	0	50
41	120	51	100
121	350	101	200
351	420	201	300
420	600	301	500

Table 2: Categories of AQI and their meanings (as an indication of health concern) in USA and Thailand.

<table>
<tr><th colspan="3">USA-EPA Standard</th><th colspan="3">Thailand-DPC Standard</th></tr>
<tr><th>AQI values</th><th>Levels of air quality</th><th>Colors</th><th>AQI values</th><th>Levels of air quality</th><th>Colors</th></tr>
<tr><td>0-50</td><td>Good</td><td>Green</td><td>0-50</td><td>Good</td><td>Blue</td></tr>
<tr><td>51-100</td><td>Moderate</td><td>Yellow</td><td>51-100</td><td>Moderate</td><td>Green</td></tr>
<tr><td>101-150</td><td>Unhealthy for sensitive groups</td><td>Orange</td><td rowspan="2">101-200</td><td rowspan="2">Unhealthy</td><td rowspan="2">Yellow</td></tr>
<tr><td>151-200</td><td>Unhealthy</td><td>Red</td></tr>
<tr><td>201-300</td><td>Very unhealthy</td><td>Purple</td><td>201-300</td><td>Very unhealthy</td><td>Orange</td></tr>
<tr><td>301-500</td><td>Hazardous</td><td>Maroon</td><td>301-500</td><td>Hazardous</td><td>Red</td></tr>
</table>

RESULTS AND DISCUSSION

In Step 1, proper relationship between MODIS's Band 3 (Blue) and Band 7 (MIR) was investigated first. It was found from about 830 samples, in case of the aerosol free days, that the relation of the observed radiances in Blue band (Band-3) and MIR band (Band 7) can be summarized as follows (Figure 2):

$$RF(Blue) = 0.3RF(MIR) \quad (4)$$

where RF is the measured radiance at each specified band.

In general, the MIR band (Band 7) was found not sensitive much to changes of the near-ground PM level observed in the study area, therefore, it was used as a reference to compute relation of the radiance change (ΔDN) in the Blue band due to the presence of PM loading in the atmosphere based on the following relations:

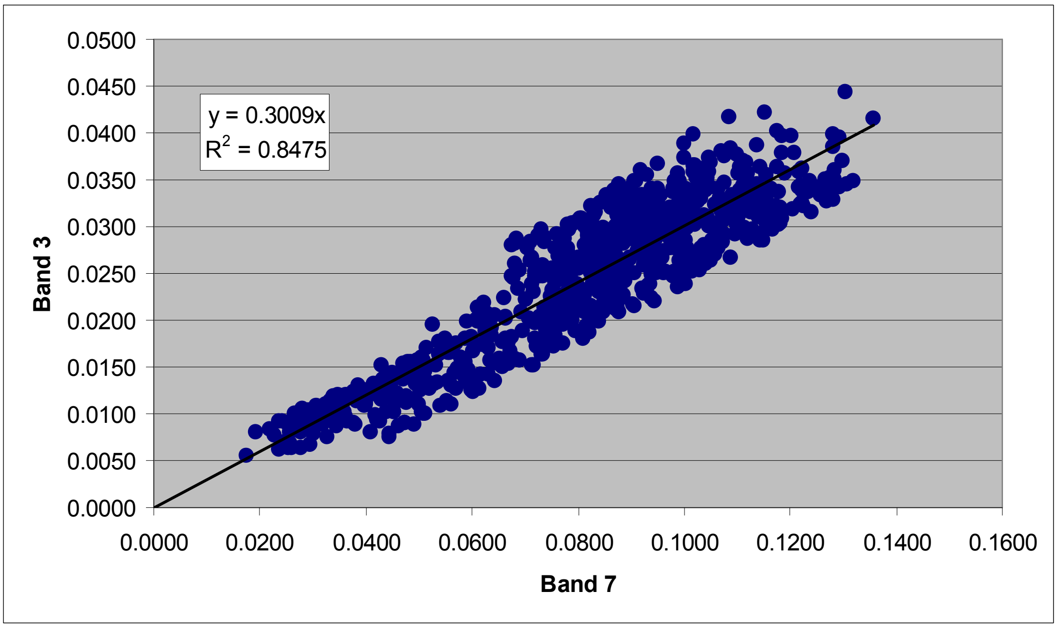

Figure 2: Linear relation between observed radiances of MODIS's Blue band (Band-3) and MIR band (Band 7) in case of the aerosol free days over the study area (Eq.4).

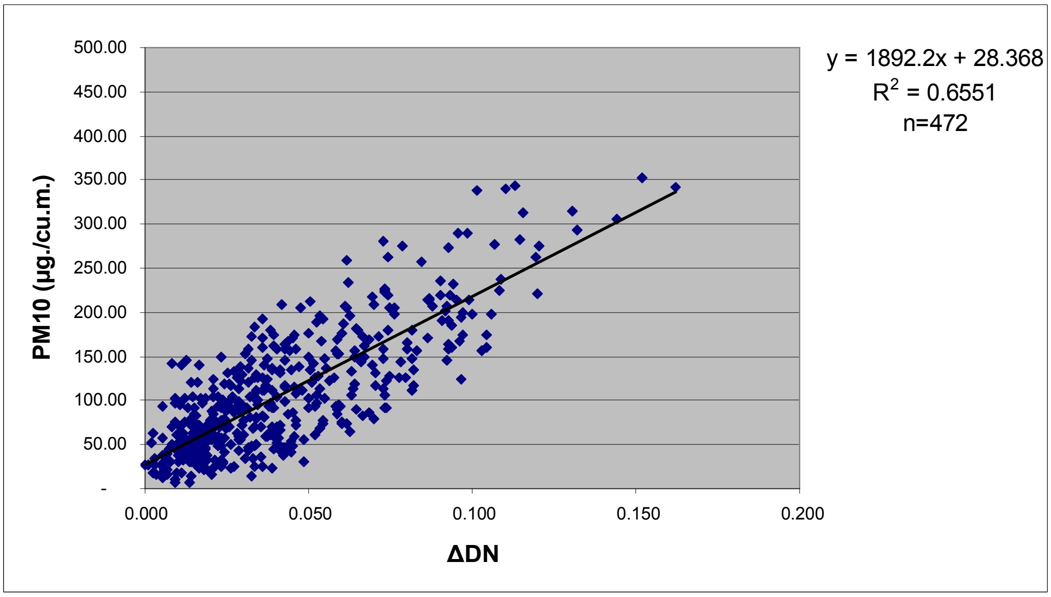

Figure 3: Linear relation of the observed radiance change in the Blue band (ΔDN) due to the presence of PM loading and the observed PM10 at ground stations in use (Eq.5).

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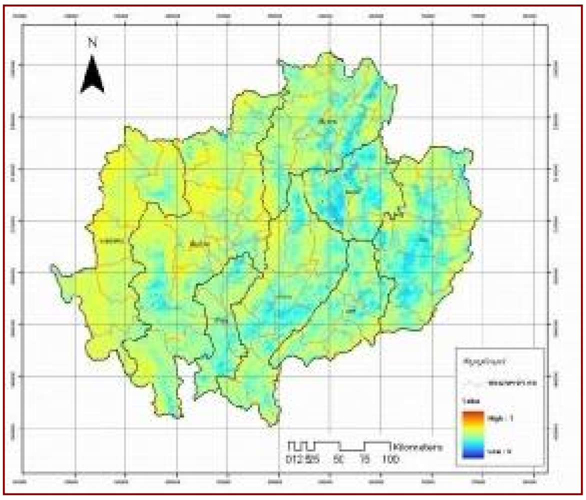
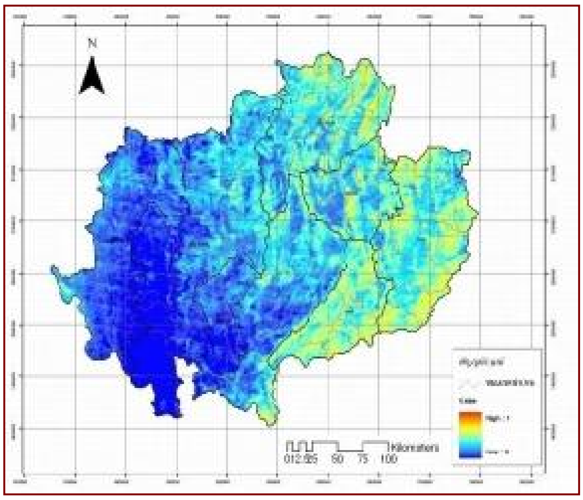
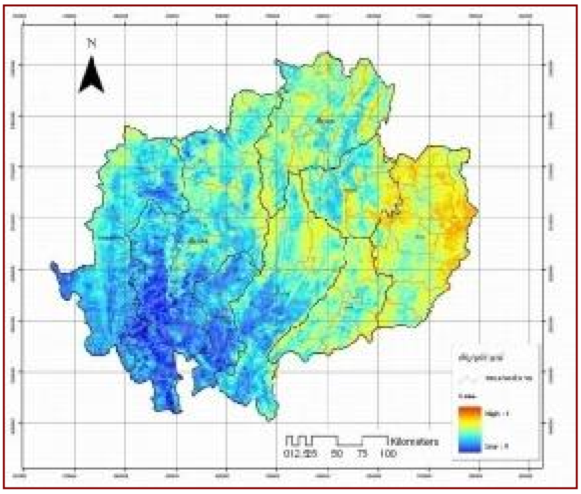


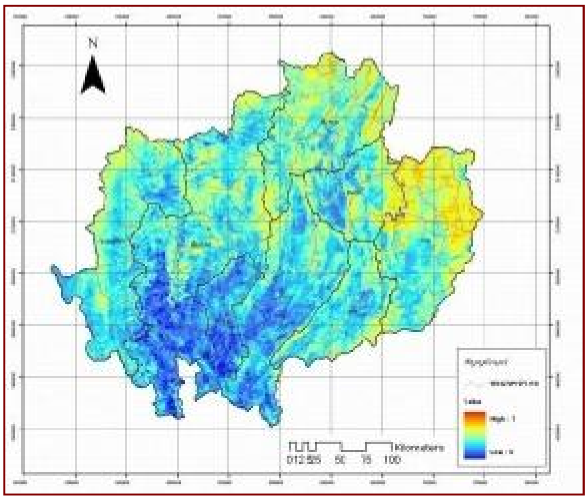
(a) 10th February 2010



(b) 11th February 2010

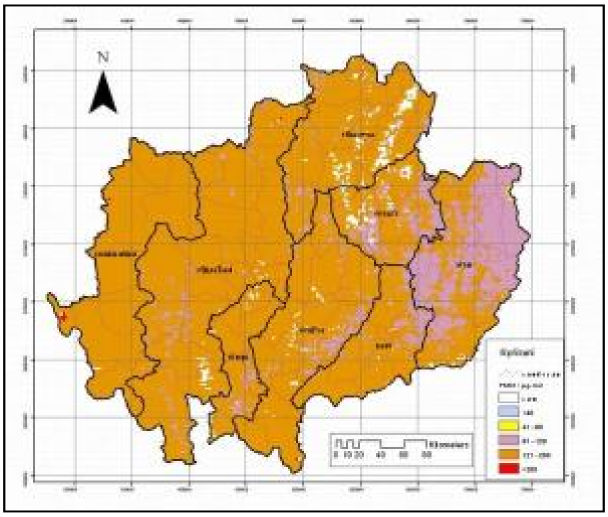


(c) 8th March 2010

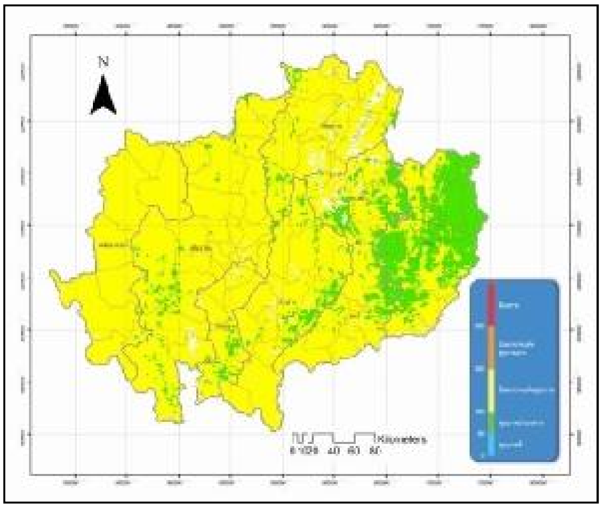


(d) 24th March 2010

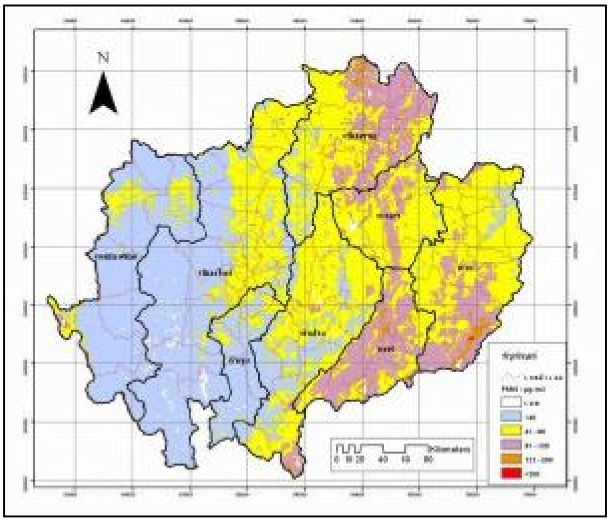
Figure 4: NDAI maps for four chosen dates of the study area.



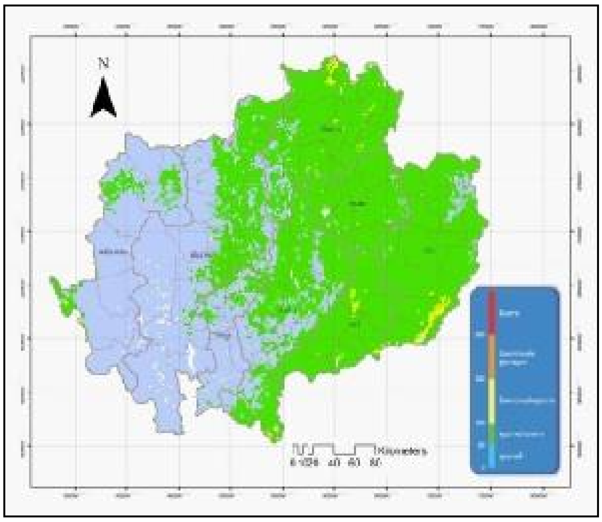
(a1) PM10 (10th February 2010)



(a2) AQI (10th February 2010)

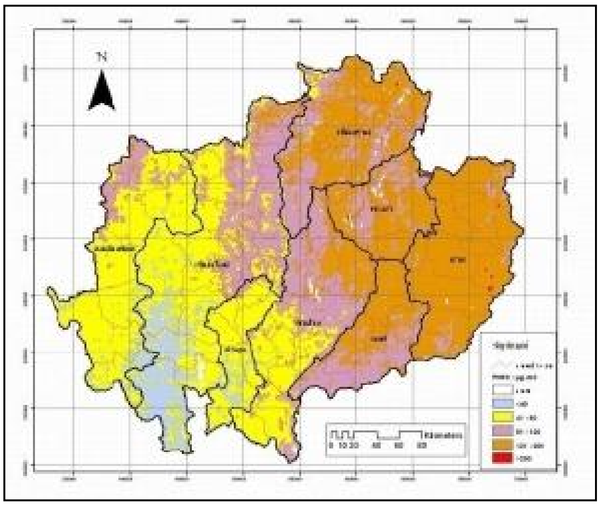


(b1) PM10 (11th February 2010)

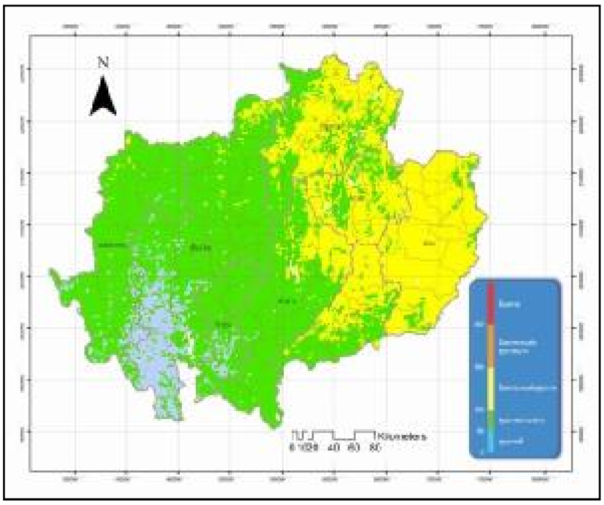


(b2 AQI (11th February 2010)

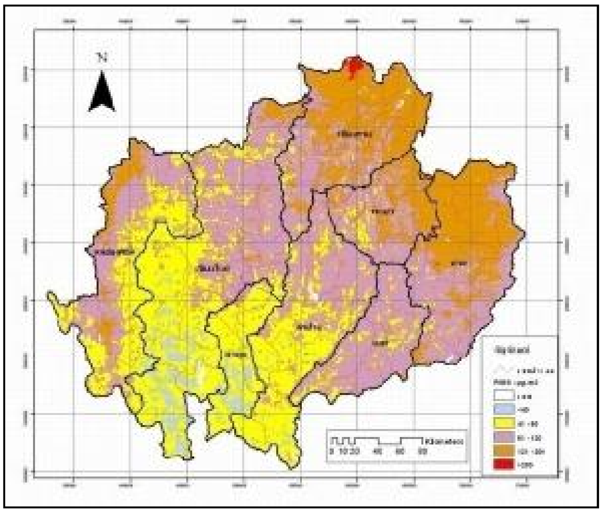
Figure 5: PM10 and AQI maps for four chosen dates of the study area.



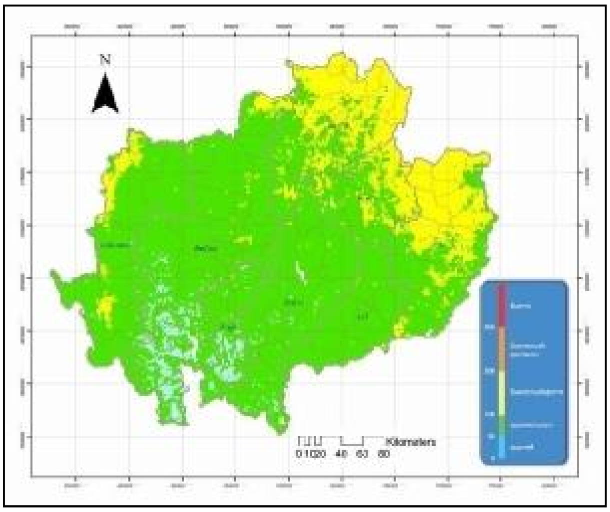
(c1) PM10 (8^{th} March 2010)



(c2) AQI (8^{th} March 2010)



(d1) PM10 (24^{th} March 2010)



(d2) AQI (24^{th} March 2010)

Figure 5: PM10 and AQI maps for four chosen dates of the study area (continued).

$$\Delta DN(Blue) = RA(Blue) - RF(Blue) = RA(Blue) - 0.3RF(MIR) \qquad (5)$$

where RA is the measured radiance at each specified band in cases that include PM loading in the atmosphere.

Knowledge of the ΔDN expressed in Eq.5 can then be employed to estimate amount of the PM10 level of interest based on this derived relation (Figure 3):

$$PM10 = 1892(\Delta DN) + 28.4 \qquad (6)$$

This relation was found based on a set of 472 data pairs of the ΔDN and PM10 level gained in the study area with $R^2 = 0.6551$.

In Step 2, the gained relation in Eq. (4) was used to generate PM10 density map using newly-introduced index NDAI (Normalized Differential Aerosol Index) defined as

$$\mathrm{NDAI} = \frac{\mathrm{RA(Blue)} - 0.3\mathrm{RF(MIR)}}{\mathrm{RA(Blue)} + 0.3\mathrm{RF(MIR)}} \tag{7}$$

This relation was applied to formulate the NDAI map for four dates with relatively high recorded PM pollution ($10^{th}/11^{th}$ February 2010 and $8^{th}/24^{th}$ March 2010) and results are shown in Figure 4.

In Step 3, the PM10 density maps were produced from Eq.6 and the their associated AQI maps were also constructed from Eq.3. Results are shown in Figure 5.

It is found that on the 10^{th} February 2010, most provinces in the study area were experienced very high amount of PM pollutant (121-200 $\mu g/m^3$) except in Nan Province that majority of the area still has high level of the predicted PM data (81-120 $\mu g/m^3$). The NDAI map shows more subtle spatial variation but similar pattern can still be seen with higher NDAI values appear on the western side and its lower values on the eastern side. The situation is better in the following day as levels of predicted PM10 in most areas are at low or moderate states only, except at some provinces on the eastern side, i.e. Chiang Rai and Phrae. On 8^{th} March 2010, most areas in the eastern side are having very high PM10 level while areas in the middle and the western parts experience less severe situation. The least severe zone (low level of PM10) appears in the southern part of Chiang Mai Province. On 24^{th} March 2010, general pattern of the PM10 distribution is similar to that on 8^{th} March except that the high PM10 state is more prevalent in the central part of the study area and the extremely high state of PM10 is quite visible in the northernmost part of the Chiang Rai Province.

CONCLUSIONS

In this study, the MODIS data in Band 3 (Blue) and Band 7 (MIR) were used to estimate PM10 aerosol density resulted from the widespread forest fires in the upper-northern Thailand. Results of the study suggest that variation of the observed near-ground PM10 (as measured by the PCD) has moderately strong linear relationship with amount of changes in measured radiances at Band 3 and Band 7 with $R^2 = 0.6551$. This relationship was used to create new index called NDAI (Normalized Differential Aerosol Index) to assist direct determination and mapping of PM10 density from the MODIS image data. The gained PM10 density maps can be transformed to create air quality map (AQI) for further uses in the monitoring and warning purposes of air pollution caused by the PM10 intensification by responsible agencies.

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