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PM_{10} and $PM_{2.5}$ from Haze Smog and Visibility Effect in Chiang Mai Province Thailand**

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Abstract

Air pollution from haze smog in Chiang Mai Thailand has become a serious problem, with fine particulate matter (FPM), PM_{10} and $PM_{2.5}$, as the main culprits. These pollutants have serious effects on health and affect visibility in transportation and tourism. In this study, reduction in visibility was monitored using a digital camera, video records and aerial photography. Visibility in Chiang Mai was analyzed using qualitative and quantitative methods. Visibility was directly measured by GPS and Google Earth mapping. Visibility reduction from haze events was also compared by image analysis in Deciview units. Fine particulate matter concentrations and frequency of fires in Chiang Mai were associated with visibility reduction. Forest fires increased Deciview numbers. In the dry season, the frequency of fire incidents was correlated with both PM_{10} and $PM_{2.5}$ with $r = 0.9$ (95, % CI, $p<0.05$). The reverse correlation (-r) between visual length (km) and PM_{10} and $PM_{2.5}$ were 0.64 and 0.72 at altitude 444 m with 95% CI, $p<0.05$. The reverse correlation (-r), at altitude 313 m was 0.93 for PM_{10} and 0.96 for $PM_{2.5}$ with 95% CI, $p<0.05$. The reverse correlation (-r), at altitude 324 m was 0.86 for PM_{10} and 0.93 for $PM_{2.5}$ with 95% CI, $p<0.05$. The association between visibility and FPM at low altitude was found to be more significant than at high altitude.

Keywords: PM_{10}; $PM_{2.5}$; Haze Smog; Visibility; Chiang Mai

Introduction

Chiang Mai is a large provincial centre with a population of 1,735,762, covering an area of 20,107 km^2 [http://stat.dopa.go.th. (cited on 13 February, 2017)]. This province is the northern region's most important tourist destination [7]. Air quality has long been a problem due to haze. Since 2014, wildfires have occurred with increasing frequency and size [4]. Wildfire emissions include FPM and chemical pollutants

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causing serious health and environmental impacts [10]. Furthermore, emission pollutants can reduce visibility either; the visibility index can be used as an indicator of air quality in urban areas [13]. In this study, we aim to identify the association between PM_{10}, $PM_{2.5}$ and visibility during wildfire events. In 2016, more than 1,600 wildfires were reported, affecting more than 36.5 km^2 (Table 1). The highest impact area was in Chiang Mai province.

Table 1 The annual comparison between frequency of fire incidents and the impact area (km^2) in 8 provinces in northern Thailand

Provinces	**2012**		**2013**		**2014**		**2015**		**2016**	
	time	**km^2**	**time**	**km^2**	**time**	**km^2**	**time**	**km^2**	**time**	**km^2**
Chiang Mai	865	10.14	1,361	23.54	937	14.64	1,179	20.42	1,602	37.19
Mae Hong Son	413	4.05	506	4.76	429	4.73	140	6.22	378	7.64
Lampang	242	2.37	304	3.14	375	2.83	399	4.79	465	5.44
Lamphun	219	2.52	166	2.35	238	3.17	297	5.75	319	8.50
Chiang Rai	181	1.50	99	1.15	91	0.14	147	1.83	164	4.11
Phayao	76	0.51	38	0.32	36	0.27	62	0.70	122	2.12
Phrae	158	2.38	147	1.63	111	0.37	140	1.63	139	3.56
Nan	29	0.51	123	2.04	88	0.01	78	1.51	148	2.92
Total	**2,183**	**23.98**	**2,744**	**38.93**	**1,031**	**26.16**	**2,183**	**42.85**	**3,337**	**71.48**

Source: Forest Fire Control Division National Park, 2017

Materials and methods

1) Site description and sample collection

The study sites in Chiang Mai are shown in Figure 1. The criteria for site selection included difference in altitude and land use. In this case, the visibility effect and haze aerosol were compared at different altitudes. Forest fires may occur at any altitude in the mountain area, while traffic-related pollution is concentrated in the city's central business area. Two sites were therefore selected in remote mountain areas: Doi Inthanon (IN) and Doi Suthep (ST), with two additional sites in the city of Chiang Mai: Maya Department store (MY), Chiang Mai International airport (AP). Two further sites were located in residential areas: Hang Dong (HD) and Suan Dok (SD). Daily spot tests for $PM_{2.5}$ were measured between January 2017 and March 2017. Records of the frequency of fire incidents were obtained from Fire Control Department. Monthly averages of PM_{10} and $PM_{2.5}$ data obtained from 3 PCD monitoring stations at City Hall (35T), Yupparaj (36T) and Mae Chaem (M109) are shown in Figure 1.

2) Visibility measurement

Visibility data in 2013-2014 were obtained from Chiang Mai airport at an altitude of 444 m, as measured by an automatic weather monitoring system. The data in 2015-2016, from the Forest Fire Control Division were measured at altitude 324 m. Meteorological data in 2013-2016 were obtained from a monitoring station in Chiang Mai at an altitude of 313 m. In this study, the qualitative visibility was measured using a digital camera and a video recorder. The photographs were taken at different altitudes and the data compared between with fire and without fire scenarios to establish the relative visibility. The visual ranges (VR) were measured from the photo taken point to the reference point by GPS and Google Earth mapping.

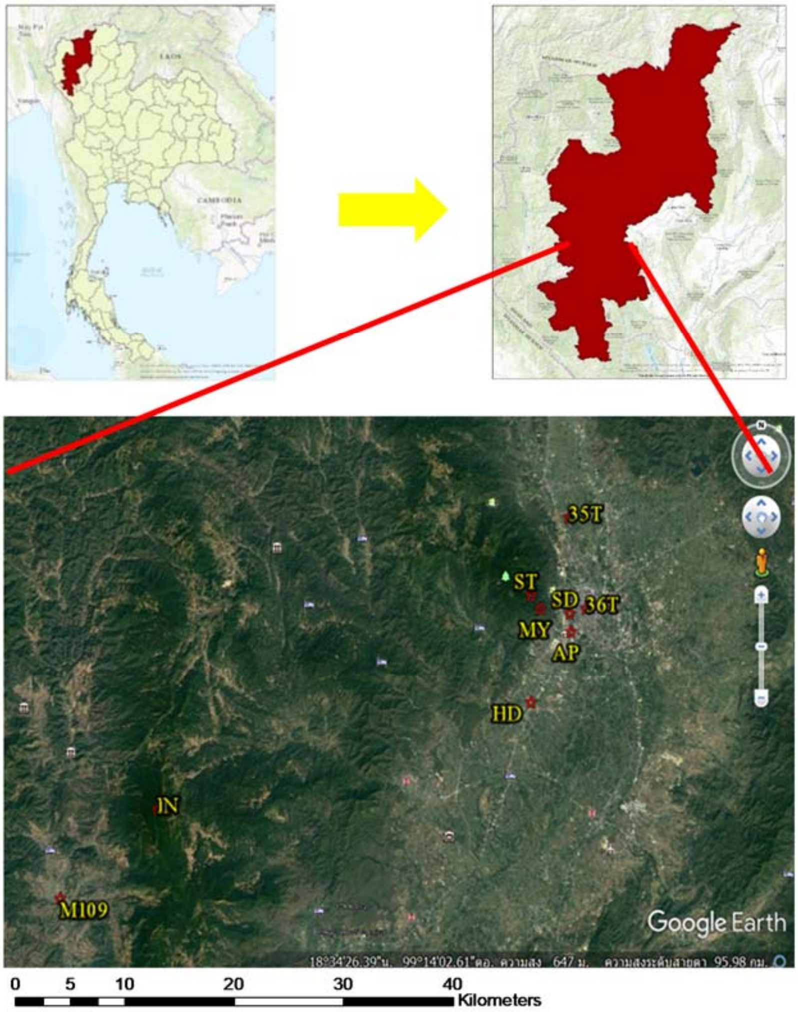

Figure 1 Site locations and air quality stations (IN = Doi Inthanon, ST = Doi Suthep, AP = Airport, HD = Hangdong, SD = SuanDok, MY = Maya Hall, 35T = City Hall*, 36T = Yupparaj*, M109 = Mae Chaem*). It should be noted that * means PCD monitoring station.

3) Quantification of the atmospheric visibility

The visual range is the distance at which an average person can barely distinguish a dark object against the sky which is related to light intensity (E), the extinction coefficient (b_{ext}) and the visual distance, x, as shown in Eq. 1 [18]. Fine particles that are in the accumulation mode (0.1-1/μm range) are the most efficient scatterers of visible light, causing them to be major contibutors to visibility reduction in the atmosphere [19]. The Koschmeider equation in Eq. 2 was chosen to calculate the visual range (VR) related to particle concentration [9, 18]. This equation is an approximation, based on an average set of atmospheric particles. The Koschmeider equation is based on the visual range corresponding to $E/E_0 = 0.02$ in Eq. 1 when VR = Δx. The extinction coefficient b_{ext} (km^{-1}) in Koschmieder formula is equal to 3.91/VR, assuming a 2% contrast threshold [11, 20]. So the Deciview index in Eq. 3 and Eq. 4 is the function of the extinction coefficient by these assumption. In this case we concidered only the particle extinction coefficient.

$$E/E_0 = \exp(-b_{ext}\,\Delta x) \qquad \text{(Eq. 1)}$$

$$VR = \frac{1200\ \text{km.μg m}^{-3}}{\text{Particle Concentration}} \qquad \text{(Eq. 2)}$$

$$\text{Number of deciviews} = 10\ln\frac{b_{ext}}{10^{-5}/m} \quad \text{(Eq. 3)}$$

$$= 10\ln\left(\frac{391\text{ km}}{\text{VR}}\right) \quad \text{(Eq. 4)}$$

VR values from Eq. 2 were used in the Deciview haze index calculation in Eq. 4 [11]. The U.S. Environmental Protection Agency (USEPA) Notice of Proposed Rulemaking (NPR) for regional haze uses the Deciview haze index (dv) as an indicator for visibility impairment [11, 16]. A change of 1 dv corresponded to about a 10% change in light extinction and is approximately constant under the assumption of atmospheric and landscape feature conditions [17].

4) PMs measurement

PM_{10} and $PM_{2.5}$ data from 2014-2016 were measured from PCD monitoring stations at Yupparaj School (station 36T), using high volume air sampling and TEOM. $PM_{2.5}$. In this study, $PM_{2.5}$ 24h average concentrations were measured from January to March 2017. Air sampling was conducted using a personal air sampler with attached $PM_{2.5}$ cascade impactor with PTFE membrane filter for 24h per sample and 3 days per sampling point. FPM and $PM_{2.5}$ concentrations were analyzed by gravimetric method using a 7 decimal point electric balance. The co-pallarel measurements between personal air sampling and the standard method high volume air sampling have been compared in our previous paper [21], indicating that personal air sampling is an appropriate field method for the current study.

Results and discussion

1) Qualitative analysis of the visibility

The aerial photograph of Chiang Mai taken from Doi Suthep is shown in Figure 2(a) without wildfire, and in Figure 2(b) during a wildfire incident. The images illustrate the severe reduction in visibility caused by the fires. It should be noted that the measurement time in Figures 2(a) and 2(b) were slightly different. Figure 2(a) was taken at 14:49h which was not a peak traffic hour and there were no fires in the area photographed. The sky was bright and clear, with no haze or visible air pollutants from vehicles. The photograph in Figure 2(b) was taken during a wildfire incident. A haze aerosol covered all areas, from roadsides to the entire ambient environment including mountain ranges. Although vehicles could potentially be partially responsible, the dominant source of FPM was clearly the wildfire haze. In Figures 3(a) and 3(b), photos were taken in the evening at 2,255 m. In this case the dv value of 40 was higher than dv 38 in Figure 2(b), even though Doi Inthanon had less traffic than in the city. In this case, visibility was clearly reduced by smoke haze. In Figure 4, photos were taken during the peak traffic hour (4-5 pm.) in Chiang Mai city. The highest dv value (48) was found in Figure 4(b), resulting from a combination of impacts from both traffic and haze.

2) Quantitative analysis of the PM_{10}, $PM_{2.5}$ and visibility

PM_{10} Data were obtained from the monitoring station Yupparaj School (36T) in the city area. The average daily PM_{10} in January 2017 without fire was 35.7±14.8 $\mu g/m^3$ and March 2017 during the fire episode was 68.6±18.6 $\mu g/m^3$. Spot test measurement data for $PM_{2.5}$ were shown in Table 2 in comparison with the monitoring station data. Measured daily $PM_{2.5}$ in January 2017 without fire was 19.5±5.5 $\mu g/m^3$ and in March 2017 with wildfire was 56.3±28.2 $\mu g/m^3$. PM_{10} and $PM_{2.5}$ concentrations were associated with the fire events and the relative visibility in deciview units.

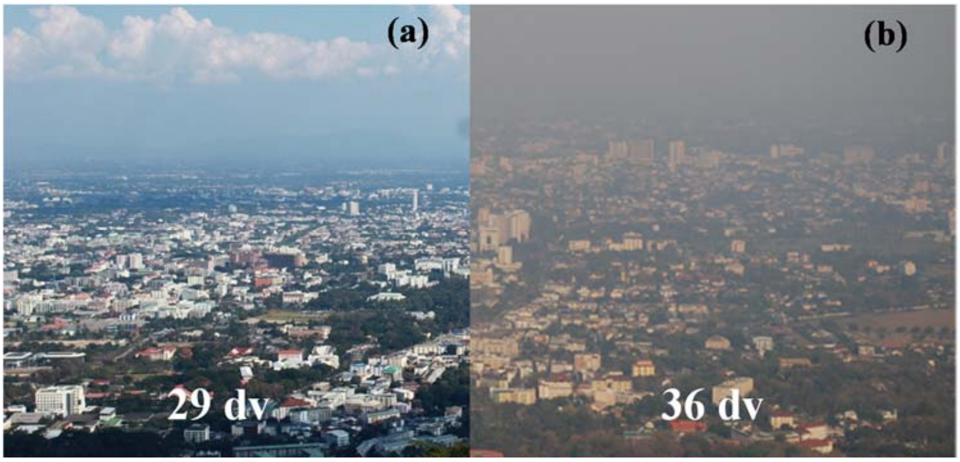

Figure 2 Photographs of Doi Suthep (ST) at N18.79138, E98.93330 at 738 m.
(a) 19 January 2017 at 2:49 pm, clean air and (b) 9 March 2017 at 5:42 pm, haze air.

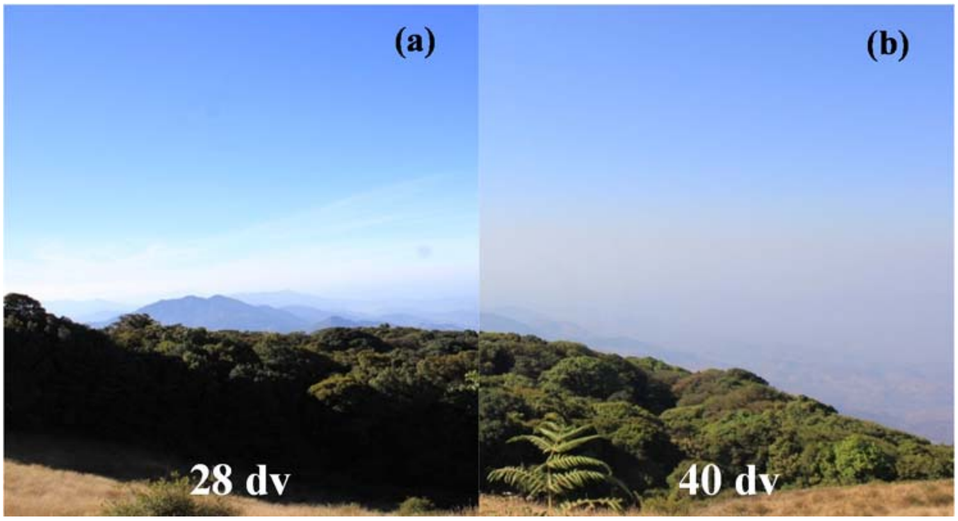

Figure 3 Photographs of Doi Inthanon (IN) at N18.56062, E98.47726 at 2255 m.
(a) 17 January 2017 at 6.05 pm, clean air (b)14 March 2017 at 5.42 pm, haze air.

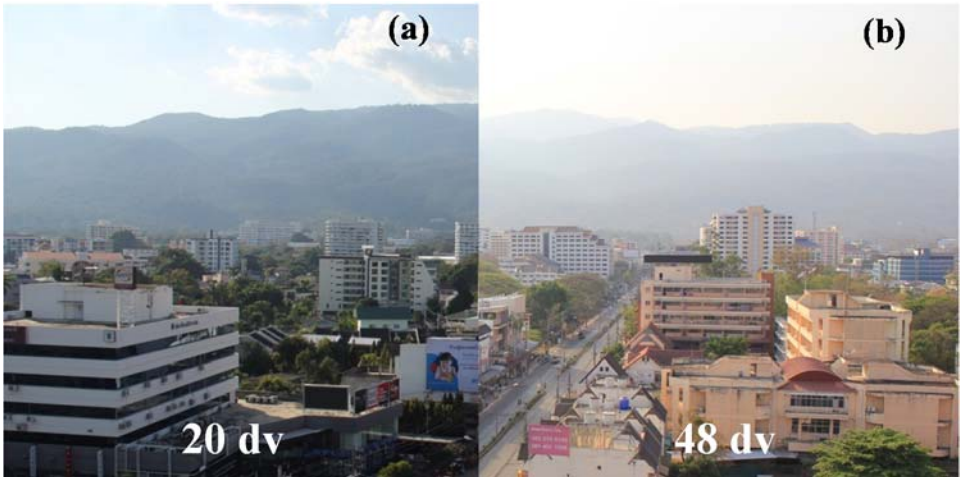

Figure 4 Photographs of MAYA (MY) at N18.79138, E98.93331 at 446 m.
(a) 20 January 2017 at 4.30 pm, clean air and (b) 17 March 2017 at 4.25 pm, haze air.

Table 2 Comparison of daily measurement and monitoring data of $PM_{2.5}$ and visibility in January 2017 (no fire) and in March 2017 (with fire)

Site	Date (no fire)	$PM_{2.5}$ (μg/m^3)		Relative visibility (dv)	Visibility (km)	Frequency of fire (time)
		PCD	Measure			
Doi Inthanon (IN)	16/01/2017	-	14.0	28.0	22.7	0
Mae Chaem (M109)		19.0	-	-	-	
Hang Dong (HD)	17/01/2017	-	15.0	-	-	0
Yupparaj (36T)		25.0	-	-	-	
City 1						
- Airport (AP)	18/01/2017	-	25.0	-	-	0
-MAYA (MY)		-	-	20.0	7.0	
-Yupparaj (36T)		24.0	-	-	-	
City 2						
- Suan Dok (SD)	19/01/2017	-	24.0	-	-	0
-Doi Suthep (ST)		-	-	29.0	20.0	
-Yupparaj (36T)		32.0	-	-	-	
Average ± SD		25.0 ± 5.4	19.5 ± 5.5	25.7 ± 4.9	16.6 ± 8.4	0

Site	Date (no fire)	$PM_{2.5}$ (μg/m^3)		Relative visibility (dv)	Visibility (km)	Frequency of fire (time)
		PCD	Measure			
Doi Inthanon (IN)	13/03/2017	-	16.0	40.0	11.4	37
Mae Chaem (M109)		37.0	-	-	-	
Hang Dong (HD)	14/03/2017	-	70.0	-	-	33
Yupparaj (36T)		45.0	-	-	-	
City 1						
- Airport (AP)	16/03/2017	-	59.0	-	-	35
-MAYA (MY)		-	-	48.0	3.0	
-Yupparaj (36T)		38.0	-	-	-	
City 2						
- Suan Dok (SD)	17/03/2017	-	80.0	-	-	40
-Doi Suthep (ST)		-	-	36.0	10.0	
-Yupparaj (36T)		43.0	-	-	-	
Average ± SD		40.8 ± 3.9	56.3 ± 28.2	41.3 ± 6.1	8.1 ± 4.5	37.0 ± 3

In March 2017 there were 33-40 wildfire incidents, with 37 in Doi Inthanon and 40 in Doi Suthep. Visibility is in the two areas was 11.4 km and 10 km, respectively. However at Maya where high density traffic is the source of aerosol, 33 fires were reported, and visibility was reduced to only 3 km.

3) Visibility correlation with PM_{10}, $PM_{2.5}$ during Wildfire episode

The association between FPM and visibility reduction was analyzed. PM_{10} and $PM_{2.5}$ data were obtained from Yupparaj station (36T) which was the nearest PCD station to the visibility measurement sites. The analyzed data are shown in Figures 5-7. The correlations between PM_{10}, $PM_{2.5}$ and visibility were $R^2 = 0.93$ and 0.96, respectively). This result supports that of Xia et al. 2017 [14] who studied the impact of particle size distribution on light extinction (especially of particles less than 2.5 μm in size). Aerosol optical properties and their impact on haze formation were associated with visibility at different altitudes. Yu, Y., et al. [15] who studied air pollution dispersion around high-rise buildings, reported similar results.

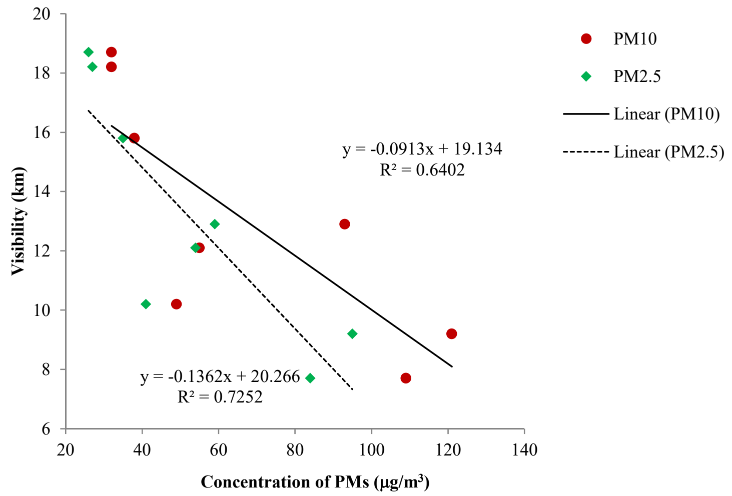

Figure 5 Visibility correlation with PM_{10} and $PM_{2.5}$ data from Chiang Mai airport 2013-2014 (N18.96415, E99.22565) at altitude 444 m.

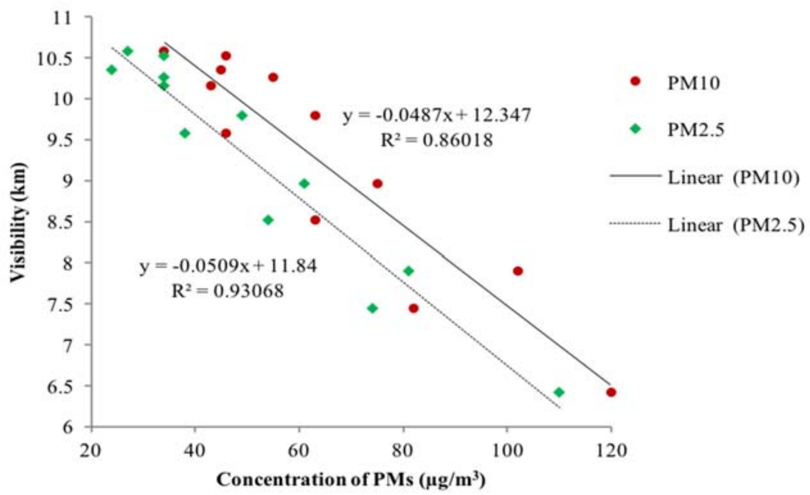

Figure 6 Visibility correlation with PM_{10} and $PM_{2.5}$ data from the Forest Fire Control Division 2015-2016 (N18.46590, E98.56630) at altitude 324 m.

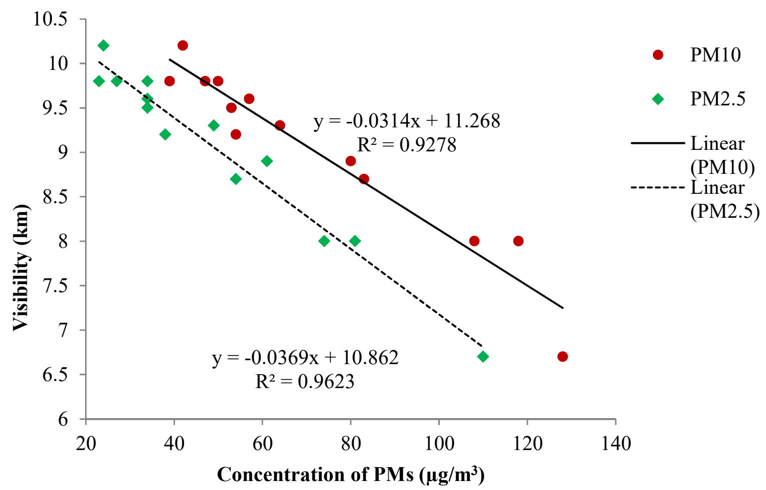

Figure 7 Visibility correlation with PM_{10} and $PM_{2.5}$ data from the Meteorological Station 2015-2016 (N18.47240, E98.58370) at altitude 313 m.

The association of PM_{10}, $PM_{2.5}$ with visibility during with and without fire scenarios were analyzed. The results are summarized in Table 2 and Figure 5-7. In the wet season, there was no fire and no correlation between PM concentrations and visibility, as shown in Figure 8. The annual trend data indicated an association between PM_{10} concentration, frequency of fires and visibility in 2016, according to data from Chiang Mai Airport.

Visibility was reduced only during three months of the year, from February to April. In this study, from December to May wildfire frequency was correlated with both PM_{10} and $PM_{2.5}$, with R^2=0.9 (95%CI, $p<0.05$). The reverse correlation between visual range (m) and PM_{10} and $PM_{2.5}$ were 0.64 and 0.72 at 444 m. with 95% CI, $p<0.05$. The correlations (-r) of PM_{10} and $PM_{2.5}$ at 324m were 0.86 and 0.93, respectively, with 95 CI, $p<0.05$. The reverse correlation (-r), at 313 m. was 0.93 for PM_{10} and 0.96 for $PM_{2.5}$ with 95 CI, $p<0.05$. Visibility at low altitude was found to be significantly inversely correlated with FPM concentration, compared with higher altitudes. The visibility reduction was evident during wildfire events. The relative visibility involved further digital imaging analysis and the development of standard visibility in the smoke fire areas.

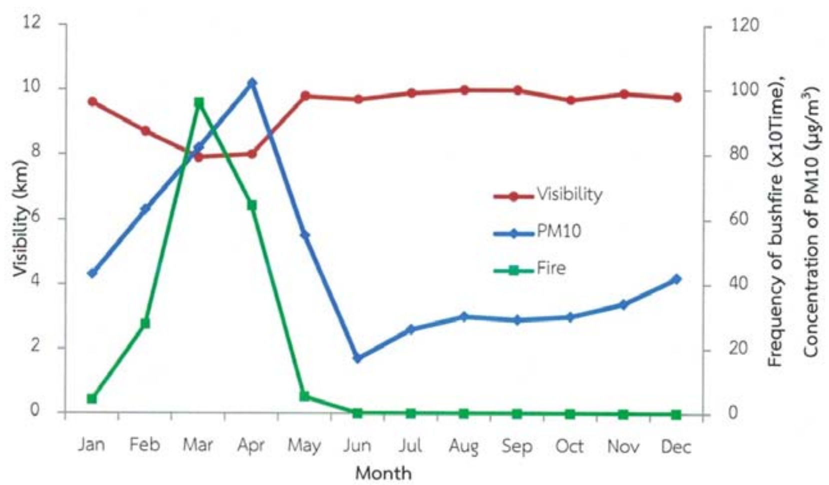

Figure 8 Correlation between PM_{10} concentration, fire frequency and visibility, by month in 2016.
Source: FFCD-Forest Fire Control Division National Park, 2017:
(available at http://www.dnp.go.th/forestfire/Eng/description.htm)

Conclusions

FPM, PM_{10} and $PM_{2.5}$ emissions from forest fires were associated with visibility reduction in Chiang Mai. The effect was more significant at low altitudes. Visibility effects were detected both by analysis of aerial photographs in Deciview, and by measurement of visibility during haze events. From the correlation between the aerosol extinction coefficients derived from visual range and particles mass, it is possible to predict the fine particle mass concentrations in the atmosphere [19, 22]. This could be applied in epidemiological assessments of population exposure to airborne particles where measurements of fine particle mass are not available. A wildfire control program should be seriously concerned to mitigate the visibility effect and public health impacts.

Acknowledgements

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