Impact on Visibility and Air Quality from Bushfire Smog and in Northern Thailand

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ABSTRACT
Bushfire events frequently occur during the dry season in northern Thailand. From December to May, this region experiences persistent dry weather and low moisture which create ideal conditions for fire. The sources could be from natural bushfires or burning of agricultural waste materials spreading to the forest. Statistical analysis of daily PM_{10}, daily visibility estimates and frequency of bush fire data from 2011 to 2013 were used to establish correlations between pollutant levels in the region and the visibility problems. Based on the monthly averages in 8 provinces, there was a significant correlation between PM_{10} and fire frequency, r = 0.93, 95%CI with $p< 0.05$. The reverse correlation (-r) between PM_{10} data and visibility distance were 0.91, 0.92 and between frequency of fire and visibility distance were 0.86, 0.83 in Chiang Mai and Chiang Rai provinces, respectively. In addition to the daily meteorological visibility data, the local visibilities were determined by photographic analysis, video-camera recordings and global positioning system (GPS). The observed images during periods without bushfires had better visibility than during bushfires. These results indicated the association between visibility and fire events. This work is aimed at creating awareness of the impact on visibility due to bushfires and its pollutants. The results could be applied in fire control planning and bush burning impact studies. Visibility monitoring in the future could involve imaging analysis, meteorological forecasting resources, including real-time satellite imaging and accurate air quality forecasts.

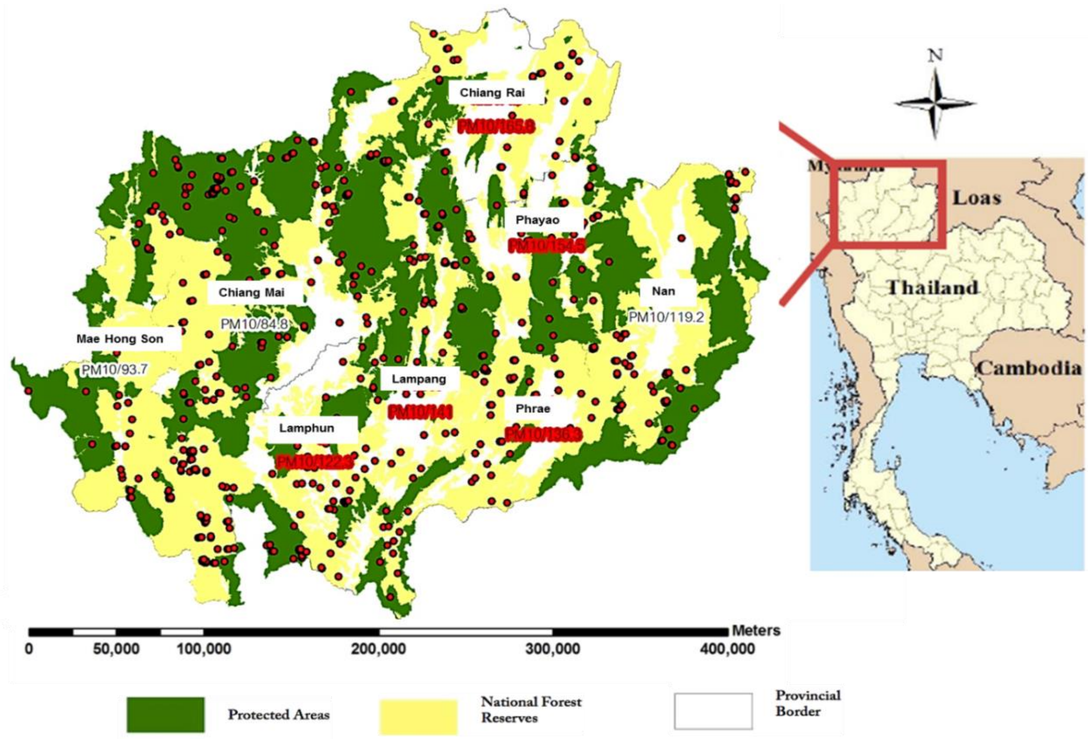
INTRODUCTION
Bushfire smog is an environmental issue in the northern part of Thailand which mainly results from the burning of agricultural waste materials in preparation for agricultural planting. These fires often spread to the forest nearby. The Forest Fire Control Division of the Royal Forest Department (FFCD), Thailand reports that forest fires occur each year during dry season from December to May. [1] The frequency and extent of bushfires from 2009 to 2013 have increased annually in the areas of far-north Thailand. [2] The information was compared and summarized in Table 1.The highest frequency of bushfires occurred in 2010. The burned areas have been surveyed by the FFCD since 2003.[1,2] Numbers of hotspots are representative of open burning in the area. The most significant fires were observed during the period of January to May, with a peak in March. An example of the impact area with hotspots in eight provinces, namely, Chiang Mai, Chiang Rai, Lamphun,

Lampang, Phrae, Nan, Phayao and Mae Hong Son is shown in Figure 1. Many research papers report that dust, smoke, fog, haze and air pollutants from bushfires effect the visibility and ambient air quality.[3,4] In this study, we aim to illustrate the impact of bushfires on both the air quality and the visibility reduction in the northern Thailand.

Table1.The annual comparison between frequency of fire (time) and the impact area (1 rai = 0.4 acre) in 8 provinces, northern Thailand

Provinces	2009		2010		2011		2012		2013	
	(time)	**(rai)**	**(time)**	**(rai)**	**(time)**	**(rai)**	**(time)**	**(rai)**	**(time)**	**(rai)**
Chiang Mai	1,388	8,945.3	1,633	11,127.8	448	2,795.9	865	6,263.5	1,361	14,541.4
Mae HongSon	395	2,477	361	2,091	176	820	413	2,499.3	506	2,940.5
Lampang	322	1,895	272	1,638	131	669	242	1,462.6	304	1,941
Lamphun	321	2,378	497	3,796	162	943	219	1,557	166	1,449
Chiang Rai	145	709.3	179	986.9	31	84.5	181	921.5	99	708.8
Phayao	139	590	117	536	39	165	76	317	38	195
Phrae	112	591	100	686	42	227	158	1,470	147	1,010.5
Nan	5	45	39	517	2	8	29	311	123	1,259.5
Total	**2,827**	**17,630.5**	**3,198**	**21,378.6**	**1,031**	**5,712.4**	**2,183**	**14,801.9**	**2,744**	**24,045.6**

Figure 1: Hotspots and PM_{10} daily average in the 8 provinces during the bushfires on 23 February 2012 http://www.dnp.go.th/forestfire/hotspot/2555/23_02_55.htm



Experimental Methods

Studied Sites and data information

The studied locations were in 8 provinces in northern of Thailand, namely, Chiang Mai, Chiangrai, Lamphun, Lampang, Phrae, Nan, Phayao and Mae Hong Son (Figure 1). Visibility data were from Meteorological Station at Chiang Mai and Chiang Rai airports. The frequency of fire records were from Fire Control Department. , PM_{10} data was obtained from Pollution Control Department, measured by beta attenuator air sampling average 24 hour intervals measured in $\mu g/m^3$.

Visibility measurement

There are several general approaches to measure visibility with a camera such as roadside camera, video records and aerial photograph.[5,6] In this study, the local visibilities were determined by photographic analysis in comparison between with and without bushfire scenarios. Qualitative measurement was illustrated from the photos taken by roadside camera, video records and aerial photographs. Quatitative visibility was analyzed in comparison to the visual distance during fire and without fire episodes. The visibility length (Lv) was directly measured by GPS and Google earth mapping. The changing in lighting conditions of the photos was analyzed from the luminosity histogram.

Results and Discussion

In the presence of dust, smoke, fog, haze or air pollutants, visibility is reduced. Low visibility is obviously a problem of transportation safety and significantly effects to environmental aesthetic reasons. For example, low visibility in Chiang Mai was dramatically illustrated by the photograph in Figure 2. This poor visualization was associated with most frequency of fires in Table 1. The visibility at ground level was directly measured as visibility length (Lv) by GPS and Google earth mapping. The result in comparison to with and without fire are shown in Figure 3. The ground level L_v of without bushfire (3a), L_v = 400 m, was higher than with bushfire (3b), L_v = 140 m. These Lv values were associated with PM_{10} average in October 2012 (34 $\mu g/m^3$) and in February 2013 (135 $\mu g/m^3$), data from www.pcd.gov.th.

Figure 2: Aerial photograph of Chiang Mai taken on 9 March 2010 at 5:42 pm, indicated severe visibility effect from the highest frequency of fire in 2010 (data in Table1)

Figure 3: The images from CCTV record from one intersection in Chiang Mai downtown were compared. The visibility lengths, L_v (a) without fire 0.40 m. (b) with fire 0.14 m.

(a) 17 October 2012 without Fire **(b) 27 February 2013 during Bushfire**

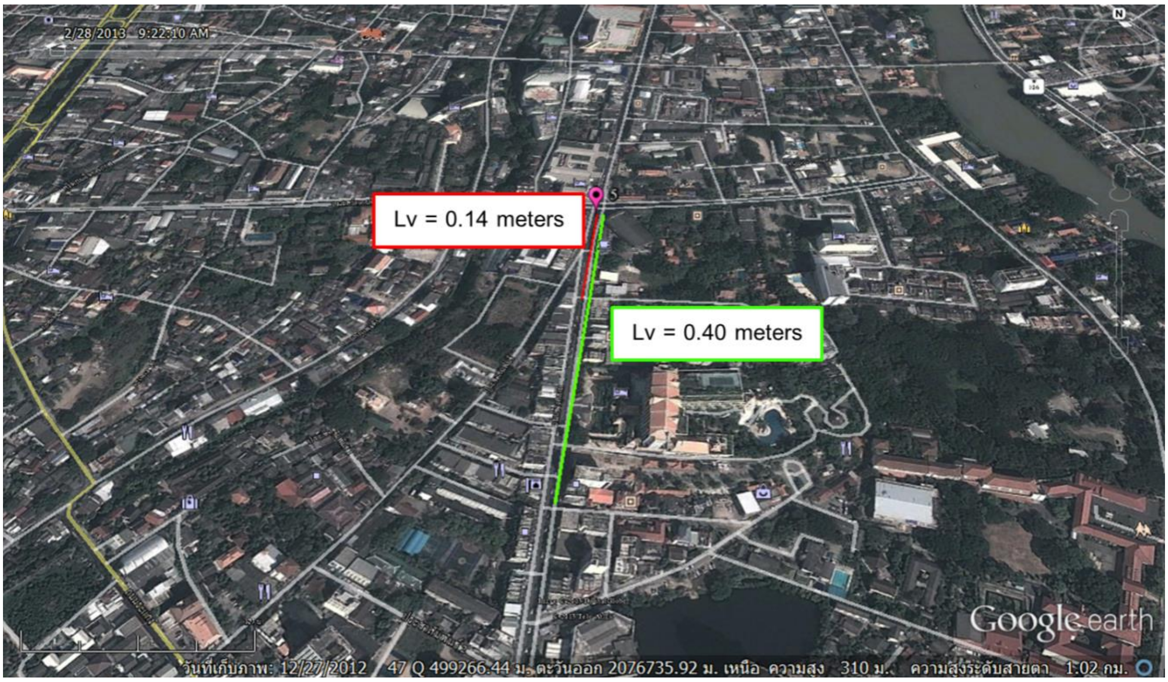
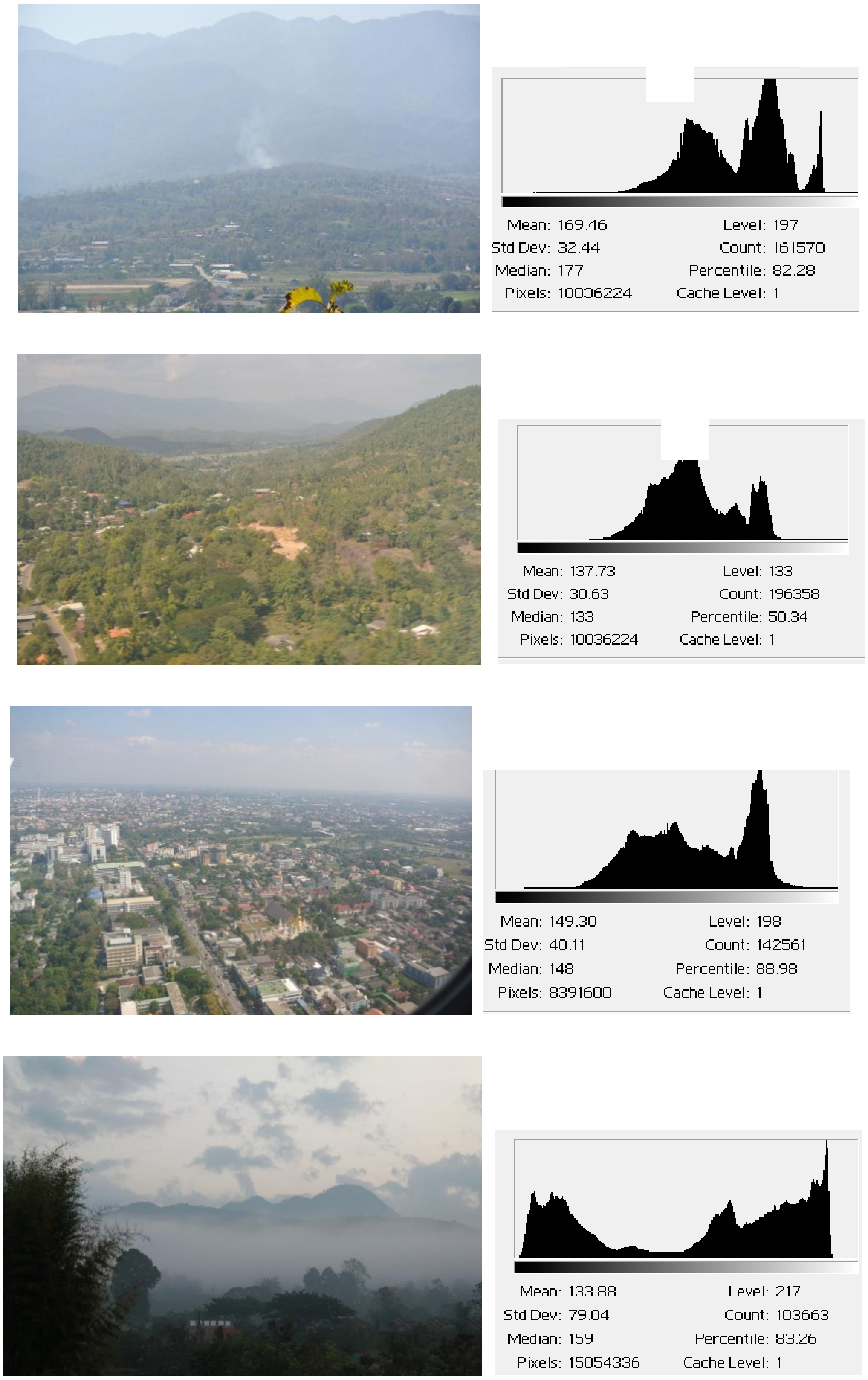


Figure 4: The ground level and aerial photographs taken in Mae Hong Son Province in January- February 2014: (A) during Bushfire (B) on the clear sunny day in the mountains range (C) urban photochemical smog in the city area (D) Morning Natural fog in small district *Note: These photos are originally used in this project only.*

A
B
C
D



Imaging analysis is a technique based on the gradient magnitude selected by applying Lambert's law with respect to changes in lighting conditions.[5,6] The visibility variations are determined by calculating the gradient of the image against illumination changes in the scene.[4] In this case, we use histogram calculation in Adobe photoshop program to calculate the luminosity of the images**.** The relative visibility can be compared from photographs and their luminosity histogram as shown in Figure 4. In the sunny afternoon, the average luminosity during the bushfire, Figure (4A) was highest which resulted from the white detection covering with smoke in the image. This indicated the visibility reduction from the bushfire smog. The urban smog in dispersed areas, figure (C) has an effect on visibility but the luminosity was less than in the case of open fire burning. However, this photochemical smog could be toxic to human health more than the carbonaceous smog. The natural fog occurred in the cold morning of winter time in tropical country like Thailand shown in figure 4D was considered as a beautiful and relaxing scene containing low luminosity.

PM_{10} correlation with Number of fire

PM_{10} increasing is directly related to the increase frequency of fire, total 2,784 times in 2013 and 2,183 times in 2012, Table 1. PM_{10} concentration and number of fire, monthly average in 8 provinces were summarized in Table 2. There is a significantly correlated between PM_{10} and fire frequency, r = 0.93, 95%CI with $p < 0.05$.

Table 2. PM_{10} concentration ($\mu g/m^3$) and number of fire (time) in 8 provinces

Month	Chiang Rai	Chiang Mai	Nan	Phayao	Phrae	Mae Hong Son	Lampang	Lumphun	Average	Bushfire
Jan,2011	52	49.35	43	58.1	57.1	30.2	34.6	51.7	46	6
Feb,2011	59.7	54.45	57.7	91.4	81	40.3	49.5	68.9	60.68	386
Mar,2011	59.4	49.5	44.6	54.8	47.1	57.4	47.3	53.4	51.03	391
Apr,2011	57.5	48.4	61.4	58.8	52.4	68.5	48.4	46.7	53.89	248
May,2011	33.8	29.25	26.1	20.2	31.6	24.1	30.0	21.4	27.83	0
Jun,2011	26.7	20	22.8	12.6	27.2	15.3	30.5	17.3	22.6	0
Jul,2011	23.4	18.525	18.2	12.8	20.1	12.6	18.4	17	18.07	0
Aug,2011	20.5	19.625	15.5	12.4	20.8	11.1	17.8	19.5	17.81	0
Sep,2011	22.9	18	17.1	13.3	22.6	13	19.3	16.9	18.51	0
Oct,2011	30	25.4	26	23.1	32.8	18.5	28.8	29.7	27.51	0
Nov,2011	37.9	25.675	32.5	35.9	47	20.3	30.3	41.3	33.34	0
Dec,2011	51.5	35.6	41.1	51.4	59.6	31.1	44.2	59.8	46.6	0
Jan,2012	47.1	36.475	45.6	50.1	66.7	29.1	52.5	63.2	48.39	107
Feb,2012	105.4	78.825	90.7	122.5	124.3	79.1	110.0	118.1	101.85	916
Mar,2012	174	109.7	125.9	138.7	121.2	221.7	116.0	113.4	135.32	920
Apr,2012	69.4	43.9	55.2	70.1	63.7	66.5	58.6	56.1	59.36	232
May,2012	37.4	22.85	27.1	44.6	31.8	27.9	30.5	26.4	30.78	9
Jun,2012	28	28.6	23.9	34.2	29.7	19.2	27.8	21.7	26.77	0
Jul,2012	21.2	25.65	18.3	11.5	22.1	13.5	23.7	16.8	19.99	0
Aug,2012	21.3	25.25	17.6	13.6	20.4	11.6	24.1	17.6	19.87	0
Sep,2012	23.1	24.725	18.5	23.4	18.2	13.4	25.7	18.4	21.36	0
Oct,2012	31.9	35.725	30.1	29	44.9	17.3	42.3	31.2	33.76	0
Nov,2012	30.5	32.5	28.6	24.8	41.8	14.9	30.8	27.5	29.11	0
Dec,2012	44.7	43.075	43.8	46.2	62.5	19.3	40.2	43.7	42.24	0

Visibility correlation **with PM_{10}**

Daily Meteorological visibility data were obtained from Chiang Mai International airport which were measured by light scattering convention method from 2 meters above ground level. The comparison of PM_{10}, number of fire and visibility length in Chiang Mai and Chiang Rai were shown in Table 3. The reverse correlation (-r) between PM_{10} data and visibility length were 0.91, 0.92 and between frequency of fire and Visibility length were 0.86, 0.83 in Chiang Mai and Chiang Rai, respectively.

Table 3. PM_{10}, number of fire and visibility length in Chiang Mai and Chiang Rai

Month	PM_{10} ($\mu g/m^3$)			Visibility (Km)		
	Chiang Mai	Chiang Rai	Average	Chiang Mai	Chiang Rai	Average
Jan,2011	49.35	52	50.68	9.4	10.45	9.925
Feb,2011	54.45	59.7	57.08	9.89	11.06	10.475
Mar,2011	49.5	59.4	54.45	9.35	9.53	9.44
Apr,2011	48.4	57.5	52.95	9.51	8.95	9.23
May,2011	29.25	33.8	31.53	10.1	12.45	11.275
Jun,2011	20	26.7	23.35	10.29	13.27	11.78
Jul,2011	18.525	23.4	20.96	10.23	13.16	11.695
Aug,2011	19.625	20.5	20.06	9.67	12.6	11.135
Sep,2011	18	22.9	20.45	9.8	12.8	11.3
Oct,2011	25.4	30	27.70	10.12	12.21	11.165
Nov,2011	25.675	37.9	31.79	10.43	12.21	11.32
Dec,2011	35.6	51.5	43.55	9.53	9.94	9.735
Jan,2012	36.475	47.1	41.79	10.08	11.91	10.995
Feb,2012	78.825	105.4	92.11	7.95	7.02	7.485
Mar,2012	109.7	174	141.85	6.56	4.36	5.46
Apr,2012	43.9	69.4	56.65	9.58	9.97	9.775
May,2012	22.85	37.4	30.13	10.16	12.37	11.265
Jun,2012	28.6	28	28.30	10.02	13.71	11.865
Jul,2012	25.65	21.2	23.43	9.8	12.62	11.21
Aug,2012	25.25	21.3	23.28	9.87	13.35	11.61
Sep,2012	24.725	23.1	23.91	9.75	12.71	11.23
Oct,2012	35.725	31.9	33.81	9.81	9.41	9.61
Nov,2012	32.5	30.5	31.50	9.95	N/A	9.95
Dec,2012	43.075	44.7	43.89	9.72	N/A	9.72

SUMMARY

Severe visibility reduction was found during bushfire events. The relative visibility involved further digital imaging analysis for the development of standard visibility in the smoke fire areas. Frequency of fires, PM_{10} and visibility are all effect to environmental quality. In the future, the local visibility data could be a data for air pollution calculation in the remote places where no monitoring stations.

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