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LEVELS AND MAJOR SOURCES OF PM-2.5 AND PM-10 IN BANGKOK METROPOLITAN REGION

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ABSTRACT

This research was the first attempt to concurrently measure and identify major sources of both PM-10 and PM-2.5 in Bangkok Metropolitan Region (BMR), Thailand. Daily averages of PM-10 were 108.1±35.5, 62.1±30.7, 61.1±25.2, and 37.9±18.9 μg m^{-3} at traffic, two residential areas, and low impact sites, respectively. Average 24-hr of PM-2.5 at the traffic site was also higher than other locations while two residential sites were relatively similar. Seasonal difference of PM-10 and PM-2.5 concentrations was distinct between dry and wet seasons. Spatial correlations of PM-2.5 among sampling sites, in term of R^2, ranged from 0.74 to 0.81 comparing to 0.67 to 0.78 of PM-10. Evidence from PM-10 and PM-2.5 concentrations showed a significant role of urban-scale meteorology in spatial distributions of both PMs within BMR.

Chemical mass balance analysis of PM-10 at the traffic site indicated that automobile emissions and biomass burning-related sources contributed approximately 33 percent each. Automobiles contributed approximately 39 and 22 percent of PM-10 mass at two residential sites while biomass burning contributed about 36 and 28 percent. PM-10 from re-suspended soil and cooking sources accounted for 10 to 15 percent at a residential site. Major sources of PM-2.5 at traffic site were automobile and biomass burning, contributing approximately 32 and 26 percent, respectively. Biomass burning was the major source of PM-2.5 mass concentrations at residential sites, accounting for 25 and 41 percent. Automobile contributed about 16 and 41 percent at residential sites, but meat cooking was significant, 19 percent, at a residential site located in the northeast of BMR. Meat cooking also accounted for 31 percent of PM-2.5 mass at a low impact site. Automobile, biomass burning, and road dust were less significant, contributed 10, 6, and 5 percent, respectively. However, approximately 25 to 33 percent of PM-10 could not be identified in this study because of the lack of some source signatures for BMR or Thailand. PM-2.5 mass had larger unexplained sources than PM-10, ranging from 27 to 47 percent partly due to inadequate source profiles of PM-2.5 in BMR.

Key words: PM-10, PM-2.5, Bangkok, Air quality, Source contribution

1. INTRODUCTION

Air quality in Bangkok Metropolitan Region (BMR), Thailand, was seriously deteriorated in the early 1990's regarding to airborne particles, carbon monoxide, and lead concentrations, especially at monitoring stations near major roadways (PCD, 2004). Gradual improvement of air quality in BMR has been observed after the Asian economic crisis partly due to the slowing down of economic expansion as well as stringent regulations. A report from the World Bank showed that air quality in BMR was better than several Asian cities, for example, Beijing, Jakarta, New Delhi and Manila (World Bank, 2003). However, problems still exist in some urban centers and near traffics, especially the problem on particulate matter (PM). Airborne fine particles in recent years have increased and started to exceed the national ambient air quality standards (120 $\mu g\ m^{-3}$ for 24-hr average of PM-10) in some monitoring stations in BMR and major cities (PCD, 2004). In 2002, the maximum 24-hr concentration of PM-10 was as high as 300 $\mu g\ m^{-3}$ (1.5 times higher than the standards).

The World Bank study on daily hospital admissions for cardiovascular and respiratory illnesses associated with air pollution levels at five hospitals in BMR. The results indicated that PM-10 (particulate matter with aerodynamic diameter less than 10 μm) concentrations in BMR associated with 4,000 to 5,500 premature deaths each year, based on the population of 10 millions. The deaths were attributed to short-term exposures to outdoor PM. Hospital admissions caused by respiratory and cardiovascular illness were higher when PM-10 concentrations were higher (Radian, 1998). An increase of 1 $\mu g\ m^{-3}$ in PM-10 was estimated to increase the mortality rate by 0.084%, chronic bronchitis cases to 3.06 per 100,000 and incidence of respiratory symptoms to 18,300 per 100,000. The study estimated that reduction of annual 10 $\mu g\ m^{-3}$ of PM-10 would reduce adverse health effect in Bangkok: 700-2,000 premature deaths, 3,000-9,300 new cases of chronic respiratory disease, 560-1,570 respiratory and cardiovascular hospital admissions. The World Bank report has found encouraging results in term of health and financial benefit. Recently study by Vichit-Vadakan (2004) examined the relationship between daily mortality and daily mortality from 1996 to 2001. The results indicated a 10 $\mu g\ m^{-3}$ change in daily PM-10 is associated with a 0.5 percent increase in total mortality. Concerns over possible adverse health and environmental effects have prompted responsible agencies to investigate and control fine PM. Unfortunately, PM-2.5 has not been in the routine measurement in BMR.

2. MAIN TEXT

Comprehensive sampling campaign for PM-10 and PM-2.5 measurements began every third day between February 2002 and January 2003 at four separated locations in BMR. The sampling locations were located along prevailing wind directions, northeast and southwest monsoon winds (Figure 1). Din Daeng (DD) station locates in the inner city next to a busy road representing a high impact (traffic) site. Two

residential sites are located on the northeast and southwest of BMR, known as Jan Krasem (JK) and Bann Somdej (BD). A low impact site, Bank Na (NA), locates in the outskirt of BMR. Each sites equipped with two low volume air samplers, MiniVol^{TM} (AirMetrics, Oregon), for 24-hr measurement of PM-10 and PM-2.5 mass concentrations. Samplers ran simultaneously at all locations, sampling at 5 LPM from 12:00 – 12:00 AM local time. This design flow rate can achieve particle cut-point of 2.5 and 10 μm. A primary reference flow device (Gilian Instrument Corp., New Jersey) was used to calibrate the flow rate prior and after the sampling. It is important to note that the MiniVol^{TM} is not a standard device designated by the U.S.EPA. The samplers have been tested and provided approximately 5 – 10 percent of comparable mass concentrations in the U.S. (Baldauf et al., 2001). Samples were alternated collected on either 47 mm stretch PTFE filters (Whatman, New Jersey) or Pallflex® quartz fiber filters (Pall Corp., Michigan) for gravimetric and chemical analyses. PTFE filters are known to have least effects from high humidity. Pre-heated of quartz fiber filters were performed to eliminate residues in the filters. Mass concentrations were determined by a single pan microbalance (Mettler Toledo, Switzerland) with 1 μg resolution. Temperature and relative humidity (RH) were controlled during filter equilibration and weighing to be within 23±5°C and 40±10%RH, respectively. Filters were kept below 4°C protected from light in individual filter holders prior to chemical analysis.

Fifteen elemental compositions of both PM-10 and PM-2.5 were determined using an Inductively Coupled Plasma – Mass Spectrometry (ICP-MS), Elan 6000 (Perkin Elmer Instrument, Connecticut). Quartz fiber filters were extracted using hot acid extraction according to Compendium Method IO-3.1 (U.S.EPA, 1999). Total carbon (TC) was analyzed using thermal technique described by Chen and Wang (1997) with PE 2400 (Perkin Elmer Instrument, Connecticut) and only PM-2.5 samples were analyzed for TC at present. Dionex DX-120 (Dionex Corp., California) was used to determine sulfate, nitrate, chloride, and ammonium concentrations in both PMs. Chemical Mass Balance (CMB8) was used in apportion major sources of the PMs (Watson et al., 2002).

Average 24-hr PM-10 and PM-2.5 at traffic site, DD, had higher concentrations than other stations, 108.1±35.5 and 69.0±28.8 μg m^{-3}, respectively. Despite of large distant (about 13 km) between JK and BD, two residential sites, they had relatively similar concentrations of average 24-hr PM-10, 61.1±25.2 and 62.1±30.7 μg m^{-3}, respectively. Similar results found for PM-2.5 concentrations at these residential sites while low impact site, NA, exhibited lower concentrations of both PMs than other stations (Table 1). Time-series data showed that both PM-10 and PM-2.5 concentrations had similar trend throughout the sampling stations within the metropolitan while daily fluctuations were observed partly due to approximately 66% of average PM-10 mass concentration accounted by particles less than 2.5 micron and influenced by meteorological conditions. PM-2.5/PM-10 ratios from all stations ranged from 0.64 to 0.67 lower than those found in the western U.S., approximately 0.75, but higher than the ratio found in the eastern U.S. about 0.52 (U.S. EPA, 2002) and Mexico City, less than 0.61 (Vega et al., 2002). However, the ratios found in BMR were in the range of those found in Spain, ranging from 60 to 90 percent (Hernádez et al., 2002; Querol et al., 2002) meaning that PM-2.5 is of

important for PM-10 mass concentrations since it constituted more than a haft of the mass in the area.

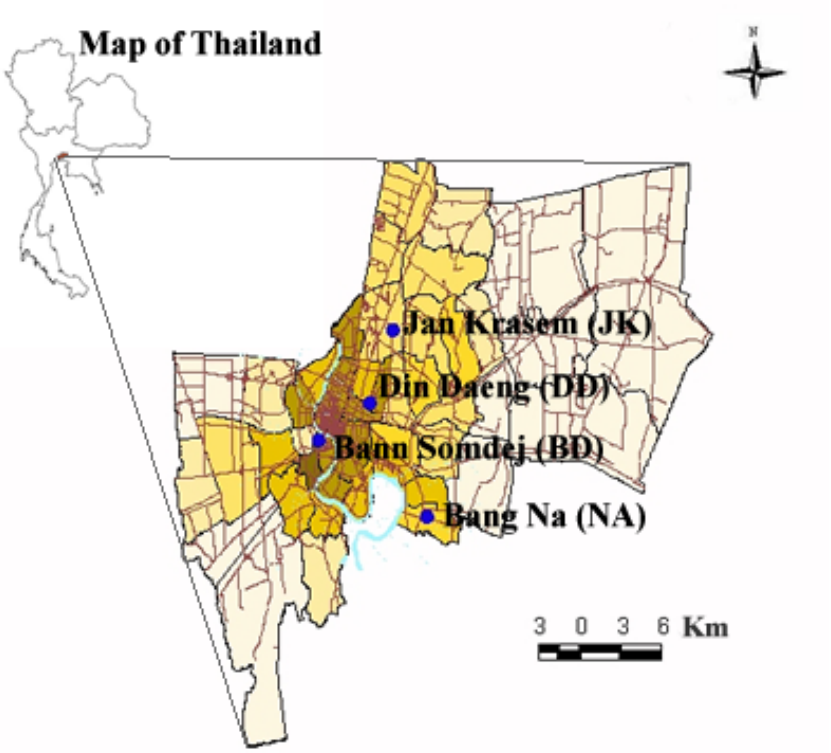


Figure 1. Map of Thailand and Bangkok Metropolitan Region (BMR) including sampling locations.

Table 1. Statistical summary of average 24-hr PM-10 and PM-2.5 in BMR during 2002 – 2003.

Average 24-hr PM-10 and PM-2.5 concentrations (μg m^{-3})						PM2.5/ PM10 ratio
Stations	Type	N	Average ± σ	Min	Max	
• DinDaeng (DD)	• PM-10 • PM-2.5	107 99	108.1±35.5 69.0±28.8	37.7 12.3	205.7 150.3	0.64 ±0.11
• Jan Krasem (JK)	• PM-10 • PM-2.5	106 103	61.1±25.2 40.9±21.4	21.3 9.2	130.0 109.8	0.67 ±0.13
• Bann Somdej (BD)	• PM-10 • PM-2.5	100 93	62.1±30.7 41.5±24.6	20.9 11.3	176.6 144.4	0.67 ±0.27
• Bang Na (NA)	• PM-10 • PM-2.5	92 88	57.6±23.9 37.9±18.9	20.7 8.0	145.1 103.9	0.66 ±0.14

Seasonal variations are divided into wet and dry seasons despite three seasons are recognized in Thailand (summer, rainy, and winter). Dry season (October – February) had higher PMs than wet season (March – September). Conditions during dry season in Asia play a major role in causing high particulate matter e.g., biomass burning and lack of rain scavenging (Ogunjobi et al., 2004). Relationships between

PM-10 and PM-2.5 mass concentrations at each station were analyzed in terms of linear regression and the results revealed that coefficients of determination (r^2) were relatively high, ranging from 0.75 to 0.83, shown in Figure 2. Equations (1) to (4) indicated that most of the slopes closed to unity meaning that factors influencing PM-10 concentrations were likely due to site-specific local conditions, e.g., local source strength, locations, meteorological conditions, etc. These local contributions could be observed from the intercepts. For instance, local contributions around DD accounted for approximately twice of the contributions in other areas, more likely from high traffics and surrounding activities.

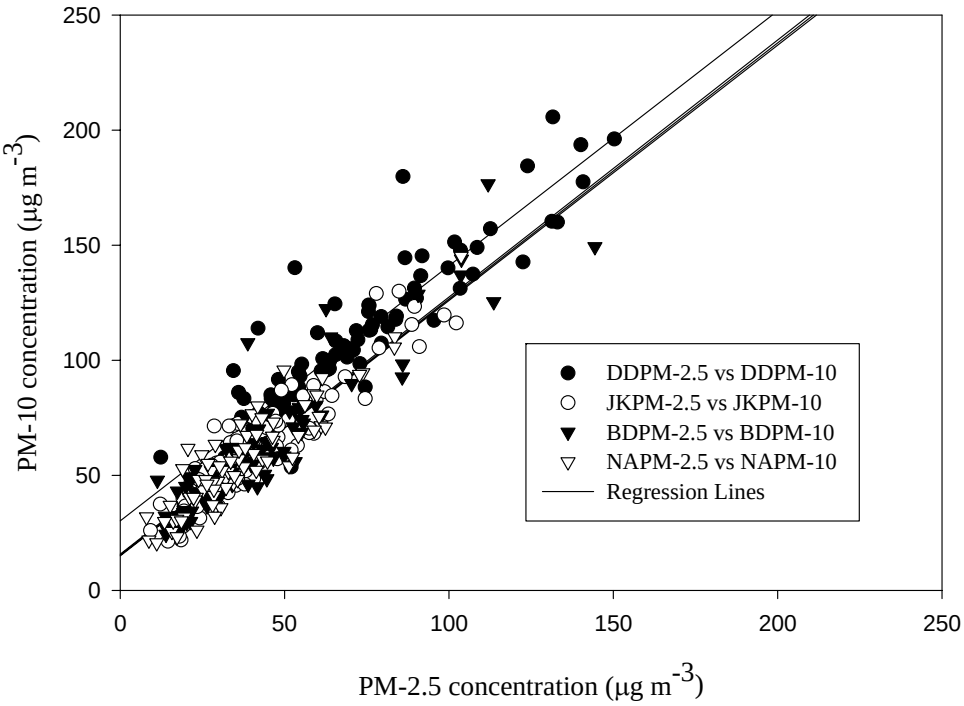


Figure 2. Correlations between PM-10 and PM-2.5 concentrations, 2002-2003.

$DD_{PM\text{-}10}$ ($\mu g\ m^{-3}$) = 1.08[$DD_{PM\text{-}2.5}$] + 32.3 ($\mu g\ m^{-3}$), r^2= 0.79 ----- (1)
$JK_{PM\text{-}10}$ ($\mu g\ m^{-3}$) = 1.03[$JK_{PM\text{-}2.5}$] + 18.02 ($\mu g\ m^{-3}$), r^2= 0.75 ----- (2)
$BD_{PM\text{-}10}$ ($\mu g\ m^{-3}$) = 1.08[$BD_{PM\text{-}2.5}$] + 15.49 ($\mu g\ m^{-3}$), r^2= 0.80 ----- (3)
$NA_{PM\text{-}10}$ ($\mu g\ m^{-3}$) = 1.11[$NA_{PM\text{-}2.5}$] + 15.33 ($\mu g\ m^{-3}$), r^2= 0.83 ----- (4)

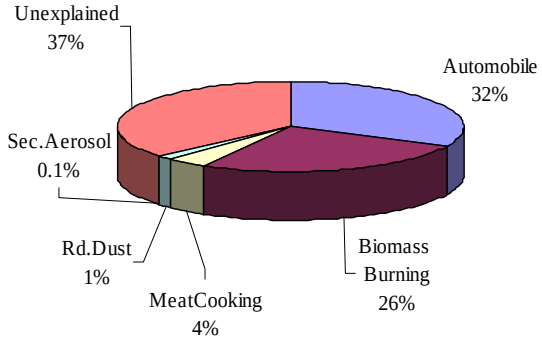
Spatial relationship between sites of PM-10 in term of coefficient of determination (r^2) ranged from 0.60 to 0.78 while PM-2.5 had better correlation, 0.74 to 0.81. Chemical analyses indicated that total carbon was a major composition in both PMs, accounting for about a half of the mass of PM-2.5 in traffic influenced station and residential stations while low impact site had total carbon less than a half of the mass concentrations. Sodium, aluminum, iron, sodium, potassium, sulfate, and nitrate were predominantly found in both PMs. Average concentrations of chemical species analyzed from PM-2.5 samples are presented in Table 2.

Table 2. Average concentrations of composition found in PM-2.5 samples.

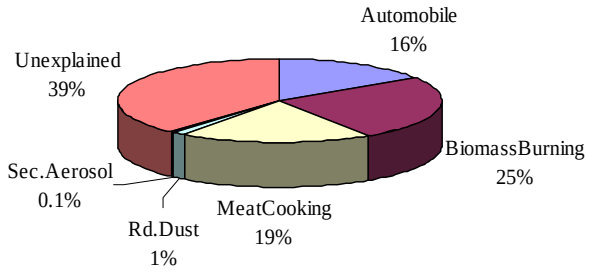
Parameter	Unit	PM-2.5			
		DD	JK	BD	NA
Mass	μg m^{-3}	69.0±28.8	40.9±21.4	41.5±24.6	37.9±18.9
TC	μg m^{-3}	38.48±19.32	21.72±12.75	21.92±13.33	17.57±11.01
NH_4^+	μg m^{-3}	0.49±0.20	0.72±0.24	0.52±0.21	0.85±0.52
Cl^-	μg m^{-3}	0.80±0.34	1.01±0.56	1.02±0.43	0.96±0.25
NO_3^-	μg m^{-3}	0.88±0.30	0.70±0.56	0.89±0.40	0.76±0.51
SO_4^{2+}	μg m^{-3}	1.84±0.55	1.33±0.59	1.66±0.49	1.96±0.57
Cr	μg m^{-3}	0.13±0.06	0.15±0.15	0.12±0.07	0.13 ± 0.06
Cu	μg m^{-3}	0.08±0.14	0.07±0.14	0.05±0.05	0.06±0.04
Fe	μg m^{-3}	1.43±0.82	1.73±1.47	1.66 ± 1.59	2.20±2.18
Mn	μg m^{-3}	0.05±0.02	0.06± 0.11	0.05±0.03	0.07±0.04
Ni	μg m^{-3}	0.26± 0.31	0.47± 0.91	0.45±0.72	0.38± 0.37
Pb	μg m^{-3}	0.18±0.18	0.28±1.02	0.15±0.13	0.22±0.17
Zn	μg m^{-3}	0.78±0.74	0.74± 0.68	0.92±0.72	1.09±0.53
V	μg m^{-3}	1.11±0.51	1.19±0.54	1.17± 0.51	1.09±0.53
Na	μg m^{-3}	1.46±1.06	1.31± 0.91	1.62± 1.11	1.31± 0.66
Mg	μg m^{-3}	0.47 ± 0.25	0.51± 0.54	0.46± 0.27	0.75±1.42
K	μg m^{-3}	0.98±0.56	0.75± 0.66	1.10± 0.88	0.93±0.67
Ca	μg m^{-3}	2.98±2.28	3.33 ±2.97	3.14 ±2.75	3.12± 2.25
Al	μg m^{-3}	1.91±1.29	2.74±3.14	2.13± 1.58	2.95 ± 2.39
Sn	μg m^{-3}	0.09±0.15	0.13 ± 0.28	0.06±0.12	0.097±0.16
As	μg m^{-3}	0.31±0.13	0.34± 0.14	0.33±0.139	0.32±0.16

Chemical compositions were used in Chemical Mass Balance (CMB8) to identify major source contributions of the PMs (Watson et al., 2002). Only five major sources were able to identify in this study with a relatively large unexplained mass, up to one-third, due to limited source profiles. Automobile was accounted for approximately 32 percent of PM-2.5 mass at traffic site, followed by biomass burning, 26 percent while cooking and secondary aerosol were less significant. Although average mass concentrations of PM-2.5 at residential sites were relatively similar, source contributions were differed from one another at residential sites in the northeast (JK) and southwest (BD) of BMR. Biomass burning was a major contribution (25 percent) to PM-2.5 mass at JK, followed by cooking (19 percent), and automobile (16 percent). PM-2.5 mass concentrations at BD were influenced by biomass burning (41 percent) while cooking was not important. In contrast, cooking was predominant (31 percent) including automobile (10 percent) and biomass burning (6 percent) at low impact site (Figure 2). Unexplained source for PM-2.5 mass ranged from 28 to 47 percent. In the case of PM-10, automobile and biomass burning were equally significant at traffic site, accounting from 66 percent of the mass (Figure 3). Automobile and biomass burning were important sources of PM-10 at other stations as well, ranging from 36 to 28 percent, but cooking and road dust contributed approximately 32 and 26 percent, respectively. Unexplained sources, however, accounted for 23 to 33 percent of PM-10 mass concentrations.

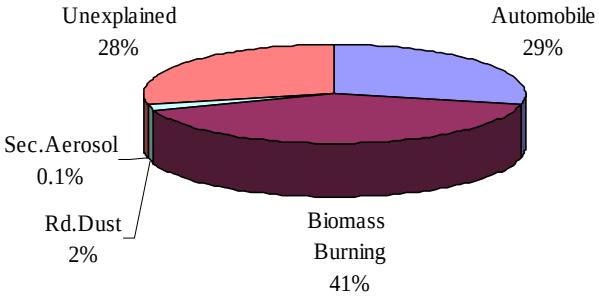
(a) Din Daeng PM-2.5



(b) Jan Krasem PM-2.5



(c) Bann Somdej PM-2.5



(d) Bang Na PM-2.5

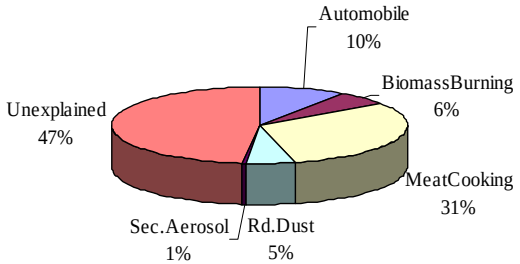
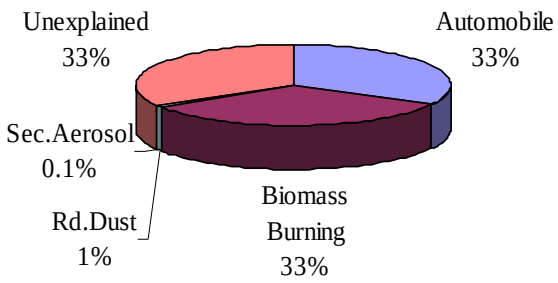
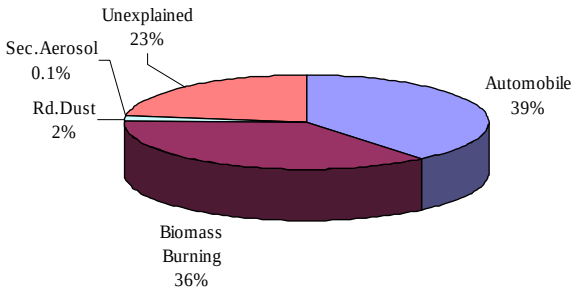


Figure 2. Estimated source contributions of PM-2.5 at each station.

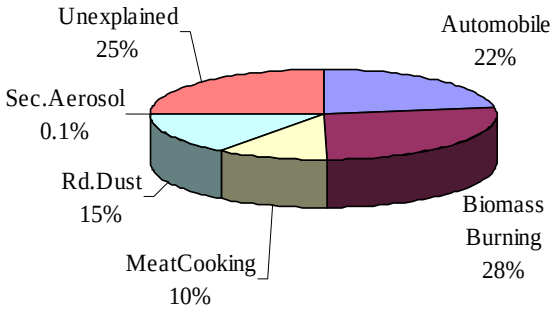
(a) Din Daeng PM-10



(b) Jan Krasem PM-10



(c) Bann Somdej PM-10



(d) Bang Na PM-10

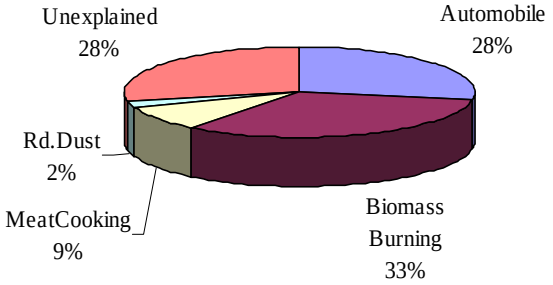


Figure 3. Estimated source contributions of PM-10 at each station.

3. CONCLUSION

Situation of PM-10 average concentrations were within ambient air quality standard of 120 μg m^{-3} for 24-hr average. While Thailand has not yet promulgated PM-2.5 standard, concentrations of PM-2.5 at traffic site exceeded 65 μg m^{-3} if a U.S. standard was considered but the concentrations were lower at residential and low impact site. PM-2.5 concentrations correlated well with each other within BMR and the correlations were better than PM-10. PM-2.5 accounted for approximately 66 percent of PM-10 mass concentrations found in BMR. Daily fluctuation of both PM-10 and PM-2.5 mass concentrations were in concert with one another across the sampling sites suggesting that urban-scale meteorology was partly influenced such phenomenon. Seasonal difference of PM-10 and PM-2.5 concentrations was distinct between dry (October – February) and wet seasons (March – September), which is typical in Asian countries with high biomass burning and lack of rain scavenging during dry season. Burning-related sources in residential sites contributed a significant portion of PM-2.5 mass, approximately 1.4-1.5 times more than automobile sources, reflecting the important sources within the areas. Major source contributions of PM-10 were automobiles and biomass burning at both traffic and residential sites, but automobile was more important. Differences in source contributions found in two residential sites when cooking and road dust were contributed approximately 10 to 15 percent, respectively, at a resident site in the northeast. Large unexplained mass was observed, especially for PM-2.5 suggesting that appropriate sources profiles were crucial for BMR to effectively identify source contribution of both PMs. Possible improvement can be made thru specific source profiles regarding to fine particulate matter, which in turn will assist an effective air quality management in the future.

4. ACKNOWLEDGEMENTS

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