Original Article

Dust and Organic Carbon in Ambient Air Pollution Associated with Increased Mortality in Chronic Obstructive Pulmonary Diseases in Thailand

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Objective: Particulate matter(PM) is associated with mortality in chronic obstructive pulmonary disease (COPD). The present study aimed to assess the association between the chemical components in PM and COPD mortality in Thailand.

Materials and Methods: The Poisson log-linear model and Bayesian hierarchical spatio-temporal with R package Integrated Nested Laplace Approximation (R-INLA) were used to determine the factor associated with COPD mortality, the database from the National Strategy and Planning Division, Office of the Permanent Secretary, Ministry of Public Health of Thailand and the concentration of five PM chemical components including dust-$PM_{2.5}$, organic carbon, black carbon, sea salt, and sulfate, the database from Modern-Era Retrospective Analysis for Research and Application, version 2 (MERRA-2) to analyze the spatial-temporal association of COPD mortality related to chemical components between 2014 to 2016.

Results: A cumulative incident rate of COPD death was 19,285 cases or 29.49 per 100,000 populations. Health region 1 located in North of Thailand had the highest mortality, 95.86 per 100,000 population while the lowest mortality was in health region 8 located in Northeast of Thailand, 12.50 per 100,000 population. Average dust-$PM_{2.5}$ and organic carbon concentrations in PM were high in North of Thailand. The spatial-temporal analysis found the association between COPD mortality and dust-$PM_{2.5}$ exposure with incidence rate ratio (IRR) 2.191 (95% confidence interval (CI) 2.102 to 2.283), and organic carbon exposure with IRR 1.074 (95% CI 1.065 to 1.084). The posterior marginal for linear predictor IRR and fitted value computed of COPD mortality showed that an increase of 1 $\mu g/m^3$ in dust-$PM_{2.5}$ and organic carbon exposure were associated with increase of COPD mortality by 64.0% and 35.3%.

Conclusion: Dust-$PM_{2.5}$ and organic carbon were associated with increase COPD mortality in Thailand. Health region 1 (North of Thailand) had the greatest magnitude of COPD mortality associated with dust-$PM_{2.5}$ and organic carbon exposure.

Keywords: COPD; Mortality; Dust; Organic carbon; Thailand

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Chronic obstructive pulmonary disease (COPD) is a chronic progressive airway disease characterized by persistent airflow limitations[1]. COPD is a major health problem worldwide. Currently, COPD is the fourth greatest cause of death globally[1]. In Thailand, the medication costs of COPD were the highest of respiratory diseases when compared with allergic rhinitis, rhinosinusitis and asthma[2]. Exacerbation of COPD leads to increased health care utilization, hospitalization, costs of treatment, a worsening quality of life, rapid declining lung function, and an increased mortality rate[3-5]. The important goal of COPD treatment by the Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines is to reduced symptom, prevent exacerbation, prevent disease progression and reduced mortality[3].

Chronic inflammation from noxious particles or gases exposure is etiology of COPD development. Cigarette smoking is the most common risk factor. Twenty-five percent of COPD, however, still occurs in non-smokers[6]. Other risk factors for COPD development are identified as genetic factors, air pollution, biomass fuels, or occupational exposure[7]. Ambient air pollution is a hot problem worldwide. Air pollution including particulate matter (PM) is a well-established risk factor for the development of various diseases including myocardial infarction, stroke, arrhythmias, increased blood pressure, Alzheimer's disease, Parkinson's disease, depression and anxiety disorders[8]. Air pollution is

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also implicated in an increased incidence of multiple respiratory diseases such as malignancy, respiratory tract infection, exacerbation of COPD and acute asthmatic attacks(8).

In Thailand, air pollution is also an important problem and it contributes to morbidity and mortality in chronic respiratory diseases patients such as COPD(9). Earlier study performed in Bangkok demonstrated that each 10-μg/m³ increase in PM_{10} (10 indicates a median aerodynamic diameter less than 10 μm) is associated with a 1.25% increase in all-cause mortality, which is higher than for the other cities that have been reported (increase risk of 0.53% for Hong Kong, 0.26% for Shanghai and 0.43% for Wuhan) and higher than multicity studies conducted in Western countries(9,10). A study from North of Thailand of COPD and PM demonstrated that $PM_{2.5}$ (2.5 indicates a median aerodynamic diameter less than 2.5 μm) found to be associated with increased daily mortality of hospitalized patients and PM_{10}, $PM_{2.5}$, NO_2, and O_3 were associated with increased daily non-accidental mortality of community dwellers(11).

Most studies obtained the value of PM from ground PM-monitoring stations(9,11). There were 77 ground PM-monitoring stations in Thailand, most stations distributed in Bangkok metropolitan region, North and East of Thailand, only 3 stations was in Northeast of Thailand, which was the largest area and highest population(12). The ground-based PM study had limitation in demonstration the association between PM exposure and COPD mortality in the overall of Thailand. Moreover, there were few studies about association between components of PM such as dust-$PM_{2.5}$, organic carbon, black carbon, sea salt, sulfate and COPD mortality.

Therefore, the present study aimed to analyze the spatial-temporal associations between a component of PM by using satellite-based method and COPD mortality in Thailand during 2014 to 2016.

Materials and Methods

This study was a cross-sectional study. The spatial-temporal association between chemical components of PM and COPD mortality rate in Thailand between January 2014 to December 2016 was explored. The study was approved by the ethics committee for human health research of the Faculty of Medicine, Khon Kaen University (HE601166).

Thailand located in the Southeast Asia region. The latitudes of Thailand are between 5.613415 and 20.464944. The longitudes are between 97.343521 to 105.636713(13). Thailand is divided into 13 health regions by government which comprises of provinces as shown in Figure 1(14), each province was located by boundary box (Bbox) from geocoding(13).

Mortality rate data

The COPD was defined in the present study using the 10th revision International Classification of Disease (ICD-10) of J40-J44 which were as the followings, J40 Bronchitis, not specified as acute or chronic, J41 Simple and mucopurulent chronic bronchitis, J42 Unspecified chronic bronchitis, J43 Emphysema and J44 Other chronic obstructive pulmonary disease(15). Most of the ICD-10 data in Thailand was coded by the primary care physicians and validated by the medical coding professionals. We gathered the COPD death cases from a death certificate record with COPD as the cause of death from the database of National Strategy and Planning Division, Office of the Permanent Secretary, Ministry of Public Health, Thailand(16). The COPD mortality rate was demonstrated in the person/100,000 populations.

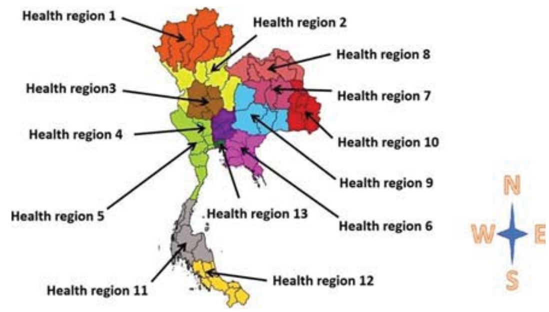

Figure 1. Health region by geography of Thailand.

The chemical components data

The air pollution data presented in the present study comprised of dust-$PM_{2.5}$ (dust surface mass concentration-$PM_{2.5}$), organic carbon (organic carbon surface mass concentration), black carbon (black carbon surface mass concentration), sea salt (sea salt surface mass concentration), and sulfate (SO_4 surface mass concentration). Each chemical component was obtained from an open-access Modern-Era Retrospective Analysis for Research and Application, version 2 (MERRA-2), by NASA's Global Modeling and Assimilation Office (GMAO)(17), which incorporates nearly real-time online aerosol data such as satellite-derived aerosol optical depth (AOD) data from Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua for over the land, the Advanced Very High-Resolution Radiometer (AVHRR) for over oceans, the multi-angle imaging radio spectrometer (MISR) instruments for bright land surfaces (such as desert areas) and also ground-based measured AOD data from Aerosol Robotic Network (AERONET). The MERRA-2 analysed the data of air pollution every 3 hours and reported the data every month with a spatial resolution of 0.5x0.625°. The data of chemical components were controlled with wind speed, temperature, and humidity(17). The average concentration of chemical components in each health region was obtained by a boundary box (Bbox) from geocoding(13). Each chemical component concentration was demonstrated by the integration of mean level of individual grid cells every month from the year 2014 to 2016.

Statistical analysis

The data analyses were calculated by R version 3.6.1 (St. Louis, Missouri, USA). The chemical components of PM data were presented as means (standard deviation), sex was presented as a number of population (percentages), average household income was presented as Baht per month, and mortality data were presented by a person per 100,000 populations. To demonstrate an association between COPD mortality and each chemical component, an incidence rate ratio (IRR) and 95% confidence interval (CI) were calculated by Poisson regression model. A univariate analysis was performed. The dependent variable was COPD death count and the independent variable was each chemical component concentration. A multivariate analysis was done. The dependent variable was COPD death count and the independent variables were each chemical component concentration, sex, average household income, and other chemical component concentrations. The posterior marginals for linear predictor incidence rates ratio and fitted values computed of COPD mortality were analyzed by R package Integrated Nested Laplace Approximation (INLA). The dependent variable was COPD count death and independent variables were each chemical component concentration, sex, average household income, other chemical component concentrations, spatial and temporal factors.

Results

The average mid-year population during 2014 to 2016 was 65,404,182 the male population was 52.87%. The average household income was 26,915 Baht/month. The average household income was highest in health region 13 which was Bangkok, the capital city of Thailand. A cumulative incidence rate of COPD mortality during 2014 to 2016 was 29.49 per 100,000 populations. The highest mortality rate was in health region 1, where located in the North of Thailand. The lowest mortality rate was in health region 8, where located in the Northeast of Thailand. The mortality rate in each region was shown in Table1. The geographic difference in mortality rate was shown in Figure 2.

The mean (SD) of five chemical components of PM during 2014 to 2016 in each health region were shown in Table 2. From 2014 to 2016, the mean concentration (SD) of dust-$PM_{2.5}$ was highest in health region 1 which was 2.454 µg/m^3 (0.183). The mean concentration (SD) of dust-$PM_{2.5}$ was lowest in health region 12 which was 1.115 µg/m^3 (0.224). The mean concentration (SD) of organic carbon was highest at health region 1 which was 8.787 µg/m^3 (1.097). The mean concentration (SD) of organic carbon was lowest in health region 11 which was 3.410 µg/m^3 (0.563). The geographic differences of each chemical component of PM were shown in Table 2 and Figure 3.

In spatial-temporal analysis, the incidence rate ratio (IRR) with 95% confidence interval (CI) was demonstrated in Table 3. For each increasing 1 µg/m^3 of dust-$PM_{2.5}$ and organic carbon associated with the mortality rate of COPD with IRR 2.446 (95% CI 2.335 to 2.540) and IRR 1.096 (95% CI 1.085 to 1.106), respectively. After adjusted sex, income, and other chemical components of PM, dust-$PM_{2.5}$ and organic carbon were still statistically significant associated with the mortality rate of COPD with adjusted IRR 2.191 (95% CI 2.102 to 2.283) and adjusted

Table 1. Population and COPD demographic data for 13 health regions between 2014 to 2016 in Thailand

Health region	Mid-year population	Male sex population	Average household income*	COPD mortality rate**
1	5,780,368	3,751,881	18,152.79	95.86
2	3,498,855	1,441,415	20,428.38	32.87
3	3,009,824	2,097,349	21,273.28	39.97
4	5,218,988	3,055,607	28,963.32	26.08
5	5,207,659	3,222,389	24,027.24	27.79
6	5,877,708	4,251,718	27,882.38	28.07
7	5,048,071	1,330,826	18,829.75	17.06
8	5,510,253	2,882,146	20,916.96	12.50
9	6,735,171	1,480,511	22,250.00	18.04
10	4,580,402	2,562,290	20,561.10	17.82
11	4,381,694	2,435,974	29,183.41	28.87
12	4,863,474	3,372,276	21,234.60	21.22
13	5,691,715	2,692,608	45,571.70	18.83
Total	65,404,182	34,576,990	26,915.00	29.49

* Household income was presented as Baht per month.
** Mortality rate was presented as the cumulative incidence rate of COPD mortality per 100,000 populations

IRR 1.074 (95% CI 1.065 to 1.084), respectively. The posterior marginal for linear predictor IRR and fixed values computed of COPD mortality was calculated and demonstrated in Table 4. Every increase of 1 μg/m^3 of dust-PM$_{2.5}$ and organic carbon associated with increase risk of COPD mortality 64.0% and 35.3% respectively.

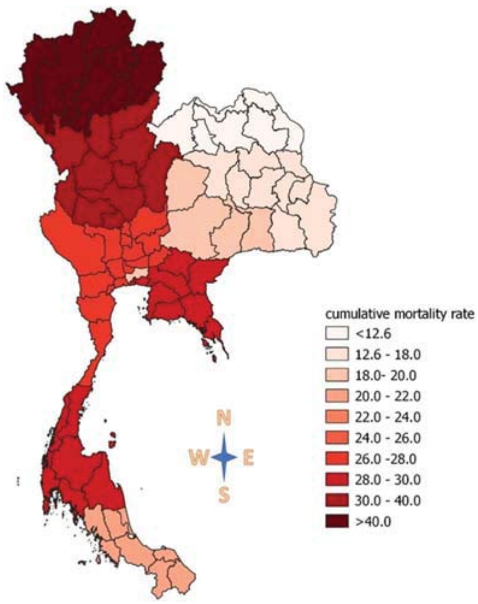

Figure 2. COPD mortality for 13 health regions in Thailand between 2014 and 2016 (per 100,000 populations).

The mortality rate of COPD in Thailand was differences in each area. The health region 8 had the lowest mortality rate, while the highest mortality rate was at health region 1. Dust-PM$_{2.5}$ and organic carbon at health region 1 were associated with increase of mortality rate with 9.105 and 7.467 times, respectively, compared with health region 8. Other health regions had different increase COPD mortality risk as shown in Table 5.

Discussion

In Thailand, COPD is still a major cause of morbidity and mortality[18]. A study of Tangcharoensathien, et al in Thailand revealed that COPD accounted for the 7th rank of death from verbal autopsy study in the year 1999[18]. The common leading cause of death were senility (11.0%), human immunodeficiency virus (10.0%), stroke (9.3%), road traffic accident (5.5%), diabetes (5.3%) liver cancer (5.3%), COPD (4.4%) and ischemic heart disease (4.1%)[18]. The database from the National Strategy and Planning Division, Office of the Permanent Secretary, Ministry of Public Health of Thailand revealed that the mortality rate of COPD increased from 2014 to 2016[16]. There were also geographic differences in the mortality rates in which the mortality rate was greatest in health region 1 located in the North of Thailand[16].

The World Health Organization (WHO) guidelines for air quality defined outdoor pollution consists of multiple substances in the air including suspended particulate matter, gaseous pollutants, and odors[16]. Suspended particulate matter (SPM) comprised of 1) total suspended particles

Table 2. The average concentration of chemical components in PM between 2014 and 2016 in 13 health regions

Health region	Dust-PM$_{2.5}$* (μg/m^3)	Organic carbon* (μg/m^3)	Black carbon* (μg/m^3)	Sea salt* (μg/m^3)	Sulfate* (μg/m^3)
1	2.454 (0.183)	8.787 (1.097)	0.970 (0.119)	5.178 (1.084)	3.363 (0.556)
2	2.393 (0.177)	7.743 (0.835)	1.120 (0.171)	7.981 (2.373)	3.791 (0.557)
3	2.170 (0.120)	8.310 (0.644)	1.440 (0.177)	8.641 (1.474)	3.665 (0.395)
4	1.875 (0.135)	8.294 (0.444)	1.661 (0.182)	15.586 (3.112)	4.111 (0.292)
5	1.795 (0.217)	7.699 (1.373)	1.590 (0.507)	19.653 (7.185)	3.357 (0.511)
6	1.529 (0.204)	6.275 (0.901)	0.972 (0.296)	26.113 (8.078)	3.308 (0.660)
7	1.964 (0.193)	8.379 (0.277)	1.421 (0.069)	7.801 (0.981)	4.631 (0.336)
8	2.169 (0.161)	8.768 (0.797)	1.262 (0.149)	5.809 (0.737)	4.972 (0.448)
9	1.815 (0.203)	7.834 (0.337)	1.322 (0.082)	9.667 (1.311)	4.197 (0.370)
10	1.724 (0.197)	8.164 (0.583)	1.005 (0.170)	9.111 (1.014)	4.060 (0.452)
11	1.270 (0.256)	3.410 (0.563)	0.510 (0.079)	45.826 (11.487)	1.540 (0.249)
12	1.115 (0.224)	3.838 (1.105)	0.646 (0.134)	37.184 (7.924)	1.575 (0.255)
13	1.710 (0.171)	7.474 (0.111)	1.488 (0.026)	27.867 (1.720)	3.941 (0.386)

Data was presented as mean (standard deviation).
* Adjusted by wind speed, temperature, and humidity

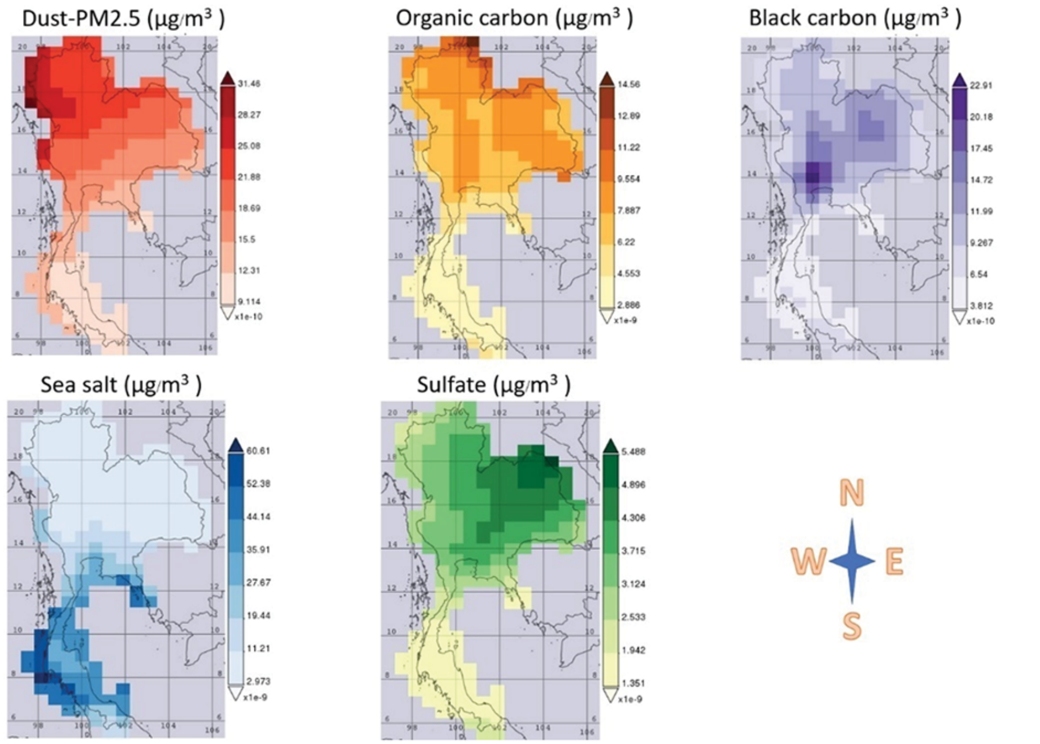

Figure 3. Average concentration by the geography of five chemical components in PM between 2014 and 2016.

Table 3. Incidence rate ratio (IRR) of five chemical components and COPD mortality

Chemical component	Mortality	
	Unadjusted IRR	Adjusted IRR*
Dust-$PM_{2.5}$	2.446 (2.335, 2.540)	2.191 (2.102, 2.283)
Organic carbon	1.096 (1.085, 1.106)	1.074 (1.065, 1.084)
Black carbon	0.648 (0.624, 0.672)	0.727 (0.698, 0.756)
Sea salt	0.983 (0.982, 0.985)	0.991 (0.989, 0.992)
Sulfate	0.868 (0.856, 0.879)	0.854 (0.842, 0.866)

* Adjusted sex, income,age, and other chemical components

(TSP), 2) suspended particulate matter with a median aerodynamic diameter less than 10 µm (PM_{10}) 3) suspended particulate matter with a median aerodynamic diameter less than 2.5 µm ($PM_{2.5}$), fine particles, ultrafine particles, mineral dust, metal dust and fumes, and carbonaceous aerosols (carbon black and organic carbon)[19]. Long term exposure to air pollution affects multiple organs especially the respiratory system. PM is the complex-suspended liquid or solid particle of various sizes and compositions in the air. Many studies have demonstrated that PM, both PM_{10}, and $PM_{2.5}$, increased hospitalization, and the mortality rate of COPD[20-24].

To the best of our knowledge, several studies were demonstrating PM associated with COPD mortality, the studies, however, linked chemical components to COPD mortality were relatively limited. It is interesting to note that, our study, was the first study to show that dust-$PM_{2.5}$ and organic carbon components in PM are the major chemical components associated with increase COPD mortality rate in Thailand. Pothirat, et al conducted a ground-based time-series study in the North of Thailand during 2016 to 2017. The study demonstrated PM_{10} and $PM_{2.5}$ were positively associated with daily mortality of community dwellers and acute COPD exacerbation[11]. The study also showed that $PM_{2.5}$ exposure increased the relative risk (RR) of daily mortality of hospitalized patients with adjusted RR 1.153 (95% CI 1.001 to 1.329)[11]. During that study period, COPD was the most common cause for hospitalization, 20% of total hospitalization[11]. It can then be hypothesized that dust-$PM_{2.5}$ and organic carbon in the present study were the major chemical components of PM_{10} and $PM_{2.5}$ because they also had high concentrations in the North of Thailand (health region 1 and 2). Bergdahl, et al performed the prospective cohort study in 317,629

Table 4. Posterior marginals for linear predictor incidence rates ratio and fitted values computed of COPD mortality

Fixed effects	Mean*	SD	2.5%	50%	97.5%
Dust (1 µg/m^3)	0.640	0.031	0.579	0.640	0.700
Organic carbon (1 µg/m^3)	0.353	0.012	0.330	0.353	0.377
Black carbon (1 µg/m^3)	-0.637	0.035	-0.705	-0.637	-0.569
Sea salt (1 µg/m^3)	-0.003	0.002	-0.007	-0.003	0.001
Sulfate (1 µg/m^3)	-0.655	0.016	-0.687	-0.655	-0.569

SD = standard deviation
* Adjusted by sex, income, other chemical components, spatial and temporal factor

Table 5. Incidence rate ratio (IRR) of dust-$PM_{2.5}$ and organic carbon and COPD mortality in each health region

Health region	Dust- $PM_{2.5}$ (µg/m^3)		Organic carbon (µg/m^3)	
	IRR*	95% CI	IRR*	95% CI
1	9.105	8.339, 9.942	7.467	6.890, 8.093
2	2.986	2.708, 3.293	2.675	2.425, 2.949
3	3.272	2.978, 3.595	3.237	2.944, 3.558
4	1.824	1.641, 2.026	2.218	2.007, 2.450
5	1.782	1.610, 1.973	2.305	2.097, 2.534
6	1.540	1.367, 1.735	2.465	2.213, 2.745
7	1.186	1.068, 1.316	1.376	1.243, 1.523
8	1.000	-	1.000	-
9	1.152	1.033, 1.285	1.522	1.376, 1.684
10	0.999	0.884, 1.128	1.445	1.304, 1.601
11	1.259	1.079, 1470	2.785	2.370, 3.273
12	0.807	0.682, 0.954	1.943	1.667, 2.264
13	1.423	1.154, 1.755	1.940	1.583, 2.378

Reference with health region 8 (lowest region of mortality)
* Adjusted by sex, income

construction workers and found that occupational inorganic dust exposure associated with an increased risk of COPD mortality with hazard ratio (HR) 1.10 (95% CI 1.06 to 1.14) and also among never-smoker COPD workers (HR 2.30, 95% CI 1.07 to 4.96)[25].

Organic carbon comprised of primary organic carbon (POC), which is derived from fossil-fuel combustion, and secondary organic carbon (SOC), which is derived from biomass-fuel combustion[26,27]. Organic carbon increases inflammatory biomarkers, including eosinophilic cation proteins and myeloperoxidases in nasal lavage fluid as well as proinflammatory cytokines IL-6, IL-8, and band-neutrophil counts in peripheral blood which indicates an involvement of both systemic and pulmonary inflammation[28]. The inflammation in COPD after dust exposure is mediated via cytotoxic T-cells, Th1, Th17, and Treg cells[29]. This may explain the mechanism of the inflammatory response in COPD patients when exposed to organic carbon and may be related to COPD morbidity and mortality.

Huang et al performed the study in healthy subjects revealed that the POC of $PM_{2.5}$ was associated with the decline of peak expiratory flow (PEF)[30] Peng et al conducted a time-series study to exam the effect of ambient levels of major $PM_{2.5}$ chemical components including sulfate, nitrate, silicon, elemental carbon, organic carbon, sodium and ammonium ions on cardiovascular and respiratory admissions. The present study showed increase in elemental carbon was associated with a 0.80% (95% posterior interval (PI), 0.34 to 1.27%) increase in risk of cardiovascular admission, and an increase in organic carbon was associated with a 1.01% (95% PI, 0.04 to 1.98%) increase in risk of respiratory admission[31]. Other chemical components were not associated with increase in risk of cardiovascular or respiratory admission[31]. Respiratory admission in the present study was defined as COPD exacerbation and respiratory infection[31]. Cakmak's study suggested organic carbon increased mortality in the elderly[32]. These studies did not address the effect directly on COPD mortality. However, they might be related to the worse outcome of COPD, as presented in the present study.

The greatest magnitude of dust-$PM_{2.5}$ and organic carbon exposure associated with COPD mortality was in the North region of Thailand. Data on ground-based stations from Air Quality in Thailand indicated the PM is the highest value in the North region during 2014 to 2016[32]. The authors implied that dust-$PM_{2.5}$ and organic carbon are the major chemical components of PM in the North of Thailand. National policy to control the concentration of dust-$PM_{2.5}$ and organic carbon in polluted ambient air is important for decrease COPD mortality.

The present study, however, has some limitations. First, the information of mortality derived from the Strategy and planning division, the Office of the Permanent Secretary, Ministry of Public Health, extracted by ICD-10. The precise diagnosis and mortality might not be confirmed. Second, the chemical components of the present study derived from the satellite database. To date, there is no study showing the correlation between the chemical components of PM and ground-based collection. Finally, the data of age is unavailable in the national database. Therefore, the COPD mortality were not analysed with age adjustment.

Conclusion

The present study found that dust-$PM_{2.5}$ and organic carbon were the major chemical components in PM associated with increase risk of COPD mortality. The North of Thailand, especially at Health region 1, was the highest region of COPD mortality. The concentration of dust-$PM_{2.5}$ and organic carbon was also high in the North of Thailand. The Bayesian spatio-temporal analysis in the present study showed statistically significant association of an increase concentration of dust-$PM_{2.5}$ and organic carbon exposure and the increase risk of COPD mortality.

What is already known on this topic?

PM in polluted ambient air was associated with COPD mortality in Thailand.

What this study adds?

The dust-$PM_{2.5}$ and organic carbon were the impotant chemical component of PM associated with COPD mortality. The evidence from the present study will support the policy and the public health for air pollution control. The effort is to decrease the concentration level of dust-$PM_{2.5}$ and organic carbon components in polluted ambient air, especially in the North of Thailand, in order to decrease COPD mortality rate.

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Potential conflicts of interest

The authors declare no conclict of interest.

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