CHEMICAL ENGINEERING TRANSACTIONS

VOL. 89, 2021

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-87-7; **ISSN** 2283-9216

DOI: 10.3303/CET2189039

Health Risk Map related to Particulate Matter Exposure in Chiang Mai, Thailand

Kannika Jarernwong[a], Shabbir H. Gheewala[b,c], Sate Sampattagul[d,e,*]

[a] Ph.D.'s Degree Program in Industrial Engineering, Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University
[b] The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand
[c] Centre of Excellence on Energy Technology and Environment (CEE), PERDO, Ministry of Higher Education, Science, Research and Innovation, Bangkok, Thailand
[d] Department of Industrial Engineering, Faculty of Engineering, Chiang Mai University, Thailand
[e] Research Unit for Energy, Economic and Ecological Management, Science and Technology Research Institute, Chiang Mai University
sate@eng.cmu.ac.th

Ambient Particulate Matter; $PM_{2.5}$, with an aerodynamic diameter smaller than or equal to 2.5 µm, has emerged as the most critical health hazard concerning air pollution. The small size enables ambient particulate matter to go through the respiratory system, easily entering the lung or blood stream. Chiang Mai is one of the cities with the highest level of $PM_{2.5}$ that exceeds the standard level of $PM_{2.5}$ concentration (10µg/m^3, recommended by the World Health Organization). High concentration levels have severe consequences for the health of the population in Chiang Mai. The objective of this study is to estimate the risk area of health impact due to exposure to $PM_{2.5}$ in Chiang Mai. This study illustrates the data of $PM_{2.5}$ concentration gathered from ground-based monitoring sites named DustBoy and data of hospital admissions from the Chiang Mai Provincial Public Health to reveal the population exposure related to human health effects such as heart diseases, chronic obstructive pulmonary disease, lung cancer, cardiovascular disease. In addition, correlation coefficient is employed to estimate the relationship between population exposure to the high ambient $PM_{2.5}$ and the health effect due to $PM_{2.5}$ pollution. The results are presented in the Chiang Mai Risk Map as a spatial pattern of population exposure using the spatial distribution method. These results support the high correlation between population exposure to $PM_{2.5}$ and health impact and strongly suggest priority areas to prevent and control air pollution and social equality in health.

1. Introduction

Ambient Particulate Matter; $PM_{2.5}$ has emerged worldwide as one of the most hazardous forms of air pollution and poses a significant risk to human health in the short and long term. Furthermore, it has been shown that an increase in the concentration of $PM_{2.5}$ heightens the risk of total deaths and total mortality (Yu et al., 2019). The International Statistical Classification of Diseases (ICD-10) has classified the diseases caused by exposure to air pollution as chronic obstructive pulmonary disease, asthma, pneumonia, influenza, acute pharyngitis, chronic rhinitis, bronchitis, cerebrovascular disease (stroke), acute ischemic heart disease, conjunctivitis, dermatitis, and lung cancers.

Thailand has been facing pollution problems for a long time, especially in the Chiang Mai province. The population is severely affected by $PM_{2.5}$ pollution, exposed to concentration levels far exceeding the recommended $PM_{2.5}$ standard levels of the World Health Organization (10µg/m^3). Furthermore, it was also ranked as the place having the worst air quality in the world with the highest level of $PM_{2.5}$ of 241 µg/m^3 recorded on 24th March 2019, only to be exceeded in the following year with the highest $PM_{2.5}$ concentration of 193 µg/m^3 on 15th March 2020. These levels highly exceed the standard levels considered acceptable for the human population. According to data released by the monitoring stations, the population had been exposed to hazardous levels of $PM_{2.5}$ for more than 44 consecutive days in 2019 and 37 consecutive days in 2020 as

Paper Received: 30 May 2021; Revised: 2 October 2021; Accepted: 15 November 2021
Please cite this article as: Jarernwong K., Gheewala S.H., Sampattagul S., 2021, Health Risk Map related to Particulate Matter Exposure in Chiang Mai, Thailand, Chemical Engineering Transactions, 89, 229-234 DOI:10.3303/CET2189039

recorded by the Thai Pollution Control Department. The high level of $PM_{2.5}$ concentration in Chiang Mai is mostly from open burning in the agriculture life cycle, urban-based pollution, transportation, and transboundary haze from nearby countries. One significant factor affecting $PM_{2.5}$ concentration is the topography of Chiang Mai, which is surrounded by high mountains which can affect the airflow and atmospheric circulation, and thus affects how pollution is distributed (Mostafanezhad and Evrard, 2020). Consequently, different areas possess different concentrations of pollution, leading to different levels of exposure and effects.

In recent decades, many studies have been increasingly concerned with the association of $PM_{2.5}$ and its impact on health. Balakrishnan et al. (2019) studied the impact of air pollution on death and life expectancy across the state of India, and Yang et al. (2018) studied $PM_{2.5}$ related to economic losses due to health effects in China. In Thailand, a study by Pothirat et al. (2019a) estimated the relation of $PM_{2.5}$ and the causes of death from cardiovascular and respiratory diseases in Chiang Dao District in Chiang Mai. Fold et al. (2020) focused on the association of $PM_{2.5}$ with the annual mortality of cardiopulmonary disease and lung cancer in Bangkok. Another study by Pothirat et al. (2019b) analyzed the mortality rate from chronic obstructive pulmonary disease, heart disease, and sepsis caused by $PM_{2.5}$ and PM_{10} in Chiang Mai. Based on the review of the available literature, there have been a few studies conducted on $PM_{2.5}$ and its impact on health in Thailand. However, while most research has been conducted on the relationship between $PM_{2.5}$ and mortality, there has been no detailed research focusing on the relationship between $PM_{2.5}$ and morbidity. There has also been no detailed study on all the diseases caused by exposure to air pollution categorized by ICD-10.

The current study aims to estimate the relation of $PM_{2.5}$ and its impact on health in all-causes of morbidity in each district of Chiang Mai, as categorized by ICD-10 in order to provide more needed research on the subject matter. The research will estimate the relationship of population exposure to $PM_{2.5}$ and human health effects in a distinct district, including 25 districts of Chiang Mai, by analysing the ground based $PM_{2.5}$ monitoring data across the province and human health impact in all-causes of morbidity. The result of this analysis is represented in a map, highlighting the spatial difference of $PM_{2.5}$ concentration and the health impact. This map provides supporting information to Chiang Mai Public Health and local health service in managing and preparing for the $PM_{2.5}$ issue in advance.

The remainder of this paper is organized as follows. The data sources, as well as the methodology are presented in Section 2. Section 3 shows the results and discussion of (i) the $PM_{2.5}$ concentration in spatial distribution, (ii) the spatial distribution of human health impact associated $PM_{2.5}$ exposure in each district in Chiang Mai, and (iii) the correlation of $PM_{2.5}$ concentration, population, and population exposure. The conclusion and limitation are illustrated in Section 4.

2. Data and methods

2.1 Study area and data

Chiang Mai province located in northern Thailand was chosen as the area of this study. Based on the latest data of the National Statistical Office in 2020, there are 25 districts, and the overall population is approximately 1,784,360 residents. Furthermore, data on admission to hospitals, determined to associate human health effects related to particulate matter exposure was collected from Chiang Mai Provincial Public Health reports. The daily $PM_{2.5}$ concentration data was collected from 62 DustBoy monitoring sites in Chiang Mai and is available at https://www.cmuccdc.org. $PM_{2.5}$ data was processed daily and averaged monthly to match the health impact data. This analysis focuses on January to April 2021 because it is the peak period of haze pollution in Chiang Mai every year.

2.2 Method

The population exposure was estimated at a region level and this recent study analysis was conducted at the district level. It was used to identify the population exposure to $PM_{2.5}$ in each region. Estimation of population exposure (Shen and Yao, 2017) can be done by Eq (1):

$$\psi_i = P_i \times C_i \tag{1}$$

where ψ_i refers to the i th region of population exposure and i refers to each as region or district, P_i refers to the population at a region location i (unit: person) and C_i refers to the particulate concentration in the same region i (unit: μg/m^3). Then, the health impact from $PM_{2.5}$ in each individual region was calculated by the population-weighted mean of population exposure to $PM_{2.5}$ (Shen and Yao, 2017); it is denoted by € and can be calculated by Eq (2):

$$€ = \frac{\sum_{i=1}^{n} \psi_i}{P_0} \tag{2}$$

where P_0 is the overall population in study area and *n* represents the total number of regions or districts in the study area (unit: person). The population-weighted mean of population exposure to $PM_{2.5}$ of each district will be presented in the Chiang Mai map using the ArcGIS Online Application.
In estimating the effects of population on $PM_{2.5}$ concentration, the correlation coefficient was applied to analyse the relation. A linear correlation coefficient can be used to consider statistical significance. A strong negative relationship is indicated by a correlation coefficient equal to -1. A correlation coefficient equal to 1 implies a strong positive relationship; it indicates a perfect positive correlation between the variables. Furthermore, a value of zero implies no relationship between the variables.

3. Result and Discussion

3.1 Spatial Distribution of $PM_{2.5}$

The monthly average $PM_{2.5}$ concentration of each 25 districts in Chiang Mai during the study period is displayed in the spatial distribution as shown in Figure 1. The color of each district represents the $PM_{2.5}$ concentration level. The red area is the highest level of $PM_{2.5}$ concentration and followed by orange, yellow, green, and blue, respectively.

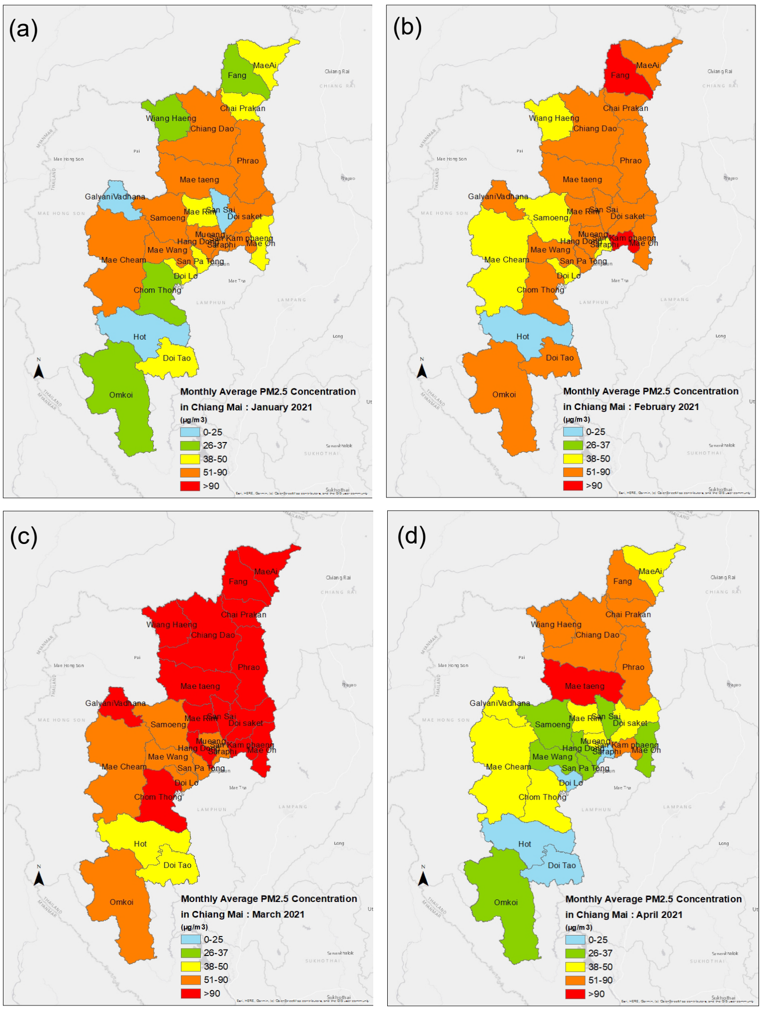

Figure 1: The spatial distribution of monthly average $PM_{2.5}$ concentration in (a) January (b) February (c) March and (b) April 2021 across Chiang Mai.

In 2021, the population-weighted means of $PM_{2.5}$ from January to April were 44.97, 61.23, 98.56, and 42.69 µg/m^3, respectively. The level of $PM_{2.5}$ concentration ranged from 18.3 to 71.86 µg/m^3 and the highest level of $PM_{2.5}$ in January was in San Kam Phaeng district. In February, the range of $PM_{2.5}$ concentration was between 21.53 and 98.33 µg/m^3 with the highest level in Fang district. Moreover, almost 85% of the population in Chiang

Mai was exposed to concentrations exceeding the standard level recommended by the Thai Pollution Control Department (50 µg/m^3). In March, the range of $PM_{2.5}$ concentration was from 37.88 to 187.6 µg/m^3 with the highest level in Chiang Dao district and the lowest level in Hot district. In this month, no one lived in good air quality area (lesser than 10 µg/m^3). In contrast, around 56% of the population lived under extreme and severe pollution and at levels that are hazardous to health (over 90 µg/m^3). In addition, the $PM_{2.5}$ concentration range in April was from 14.16 to 92.73 µg/m^3 with the highest level in Maetang district and lowest level in Doi Tao district and nearly 70% of population lived under standard air quality. However, the peak period of haze pollution in Chiang Mai, which is usually between January to April every year, occurred between January to March in 2021. And the $PM_{2.5}$ concentration in April was down compared to the previous month because of the early rainfall in April. It is consistent with the studies of Zhang et al. (2018) and Fold et al. (2020) that showed an inverse correlation between $PM_{2.5}$ concentration and rainfall, which means that $PM_{2.5}$ will reduce when it rains heavily.

3.2 Spatial Distribution of human health effect due to $PM_{2.5}$

The health impact is the number of hospital admissions from all-causes morbidity due to exposure to ambient particulate matter based on the categories in ICD-10, including chronic obstructive pulmonary disease, asthma, pneumonia, Influenza, acute pharyngitis, chronic rhinitis, bronchitis, cerebrovascular disease (stroke), acute ischemic heart disease conjunctivitis, dermatitis, and lung cancers.

From the Chiang Mai Provincial Public Health reports, the total number of populations affected by $PM_{2.5}$ reached 26,363, 23,210, and 30,164 from January to March, respectively. But the number dropped to 13,396 in April, that was associated with population exposure to the excess $PM_{2.5}$ concentration in April being less than January to March. Moreover, Figure 2 shows a trend in overall effect in population health and presents $PM_{2.5}$ health effects from all causes of morbidity. The incidence of dermatitis was ranked first in health impact attributable to pollution, followed by chronic obstructive pulmonary disease, conjunctivitis, and cerebrovascular disease.

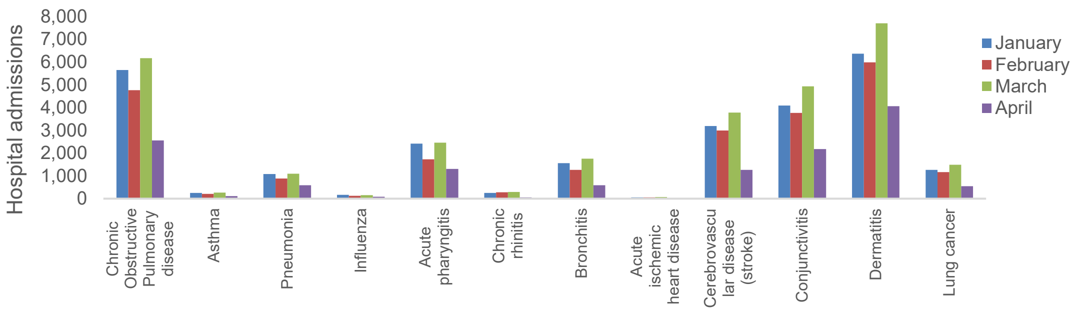

Figure 2: The number of hospitalizations from all causes of morbidity due to $PM_{2.5}$ during January to April 2021 in Chiang Mai.

The highest impacted areas in January were Muang, Mae Rim, and Fang districts with 5,863, 2,905, and 1,819 hospital admissions, respectively. At the same time, the least impacted areas were Galyani Vadhana, Wiang Haeng, and Doi Lo districts with 202, 241, and 332 hospital admissions, respectively. In February, Muang and Mae Rim districts were also the highest impacted areas, the same as in January but this time together with San Pa Thong district with 5,199, 2,776, and 1,308 hospital admissions, respectively. The least impact of morbidity was found in Galyani Vadhana, Wiang Haeng, and Doi Lo districts with 190, 231, and 335 hospital admissions, respectively. In March, the population in Muang, Mae Rim, and Fang showed the highest health impact same as in January but with a higher health effect in morbidity, amounting to 6,590, 3,667, and 2,063 patients, respectively. The lowest morbidity cases were found in Galyani Vadhana, Wiang Haeng, and Doi Lo districts, the same as in February but with more patients amounting to 227, 291, and 342 hospital admissions, respectively. The total of health impacts in April were lower than in the previous three months. The highest hospitalization rates were in Mae Rim, San Pa Thong, and Doisaket districts with 2,671, 1,411, and 828 hospitalizations, respectively. However, the most significant hospitalizations in April are still lower when compared to the previous three months. Wiang Haeng, San Kamphaeng, and Mae On districts had the lowest hospitalization rates in April with 24, 104, and 124 hospital admissions, respectively.

Moreover, the human health impact due to exposure to ambient $PM_{2.5}$ was allocated in proportion to the number of hospital admissions per area in km^2 and is displayed in spatial distribution as shown in Figure 3. This spatial pattern highlights the population concentration affected by exposure to $PM_{2.5}$ in a km^2 as different colors indicating highest population exposure concentration as red, followed by orange, yellow, green, and blue.

Figure 3 shows that Muang district had the highest health effects concentration rate in January to March with 38, 34, and 43 hospitalization/km^2. Nevertheless, in April, the hospitalization concentration rate was high in Mae Rim and San Pa Thong districts, but the amount of hospital admissions decreased from the previous three months. There were only 8 and 6 hospitalization/km^2 in Mae Rim and San Pa Thong respectively and 4 hospitalization/km^2 in Muang district. The number of hospitalizations was down in April because almost 70% of the population lived with a better air quality (under 50 µg/m^3). The hospital admissions from $PM_{2.5}$ impact in Muang district was the highest risk area in human health effects, followed by Mae Rim, and San Pa Thong. The lowest risk areas were Galyani Vadhana, Wiang Haeng, Doi Lo, San Kamphaeng, and Mae On districts. Factors that could have influence Muang district to have the highest health risk from $PM_{2.5}$ are the low topography surrounded by mountain and high population density.

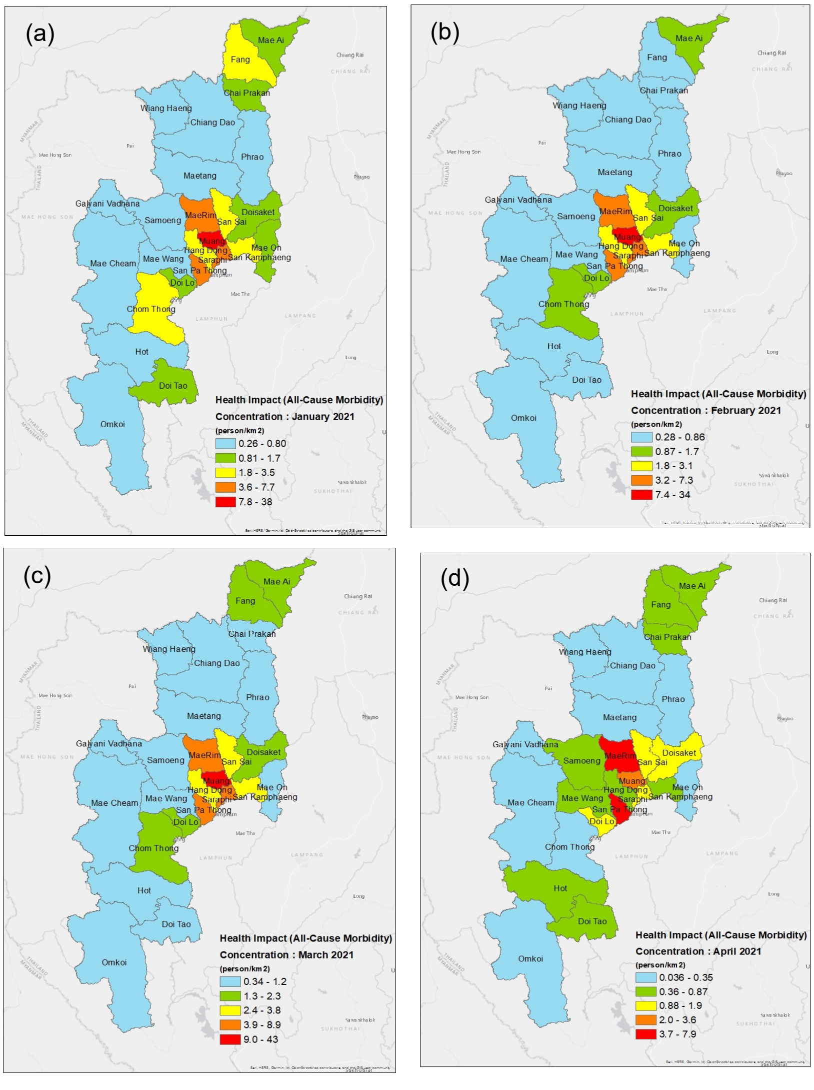

Figure 3: The spatial distribution of population weighted ambient $PM_{2.5}$ in (a) January (b) February (c) March and (b) April 2021 across Chiang Mai.

3.3 Correlation between $PM_{2.5}$ and population exposure

The relationship between $PM_{2.5}$ concentration, population, and population exposure in Chiang Mai was measured by the correlation coefficient and is presented in Table 1. The result shows the population was not related to $PM_{2.5}$ concentration with a correlation coefficient value equal to 0.06. It is consistent with the Shen and Yao (2017) study where the population does not influence the $PM_{2.5}$ concentration on a local scale. In addition, the correlation coefficient value between $PM_{2.5}$ concentration and population exposure to $PM_{2.5}$ equals 0.71, which means a strongly positive relationship. Moreover, it implied that the increase of $PM_{2.5}$ concentration leads to increased human health impacts, as indicated by the hospital admissions.

Table 1: Correlation coefficient values of $PM_{2.5}$ concentrations, population-weighted mean $PM_{2.5}$, and population exposure in Chiang Mai

	Population-weighted mean $PM_{2.5}$	Population exposure
$PM_{2.5}$ concentration	0.06	0.71

4. Conclusions

This study demonstrates the $PM_{2.5}$ concentration and the impact on human health in all-causes of morbidity due to exposure to ambient $PM_{2.5}$ in 25 districts of Chiang Mai by using the spatial distribution and highlighting each individual area. Assessing the population-weighted exposure, Muang district was the highest risk area in terms of human health effects (maximum 43 hospitalization/km^2), followed by San Pa Thong districts (maximum 9 hospitalization/km^2), and Mae Rim (maximum 8 hospitalization/km^2), while the lowest risk areas were Galyani Vadhana, Wiang Haeng, Doi Lo, San Kamphaeng, and Mae On district (maximum 1 hospitalization/km^2). Availability of data is deemed important for the efficient management of $PM_{2.5}$; lack of data complicates the needed improvement for the health care sector with regards to the quality of medicine and medical equipment, effective disease prevention and a significant decrease of medical expenses and treatment costs.

Therefore, data management initiatives should be taken, utilizing data on population, hospital admissions, and $PM_{2.5}$ concentration that are represented in a spatial distribution as a Chiang Mai risk map. The map displays the risk area that shows different levels of impact for the population of each district in Chiang Mai. This study has implication on the health risk analysis and pointing out dangers to the Chiang Mai Public Health and local decision making units in order to effectively plan for emergencies and prevent them from happening in the first place. These measures include the adequate provision of face masks to people, sufficient distribution of air filters for hospital patients, the arrangement of dust-free classrooms to avoid exposure to pollution in schools, and help raise awareness to the public. Therefore, appropriate decision making in policy should reflect the differences of existing health risks. This study has some limitations in analysing the human health impact only in terms of morbidity as hospital admissions. $PM_{2.5}$ however also affects mortality or life expectancy, which was not included in this study. Lastly, the overall hospitalizations in this study covered all causes of diseases. In the future, each disease from all-causes of morbidity will be analysed and presented in the risk area of individual diseases.

References

Balakrishnan K., Dey S., Gupta T., Dhaliwal R.S., Brauer M., Cohen A.J., 2019, The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017, The Lancet Planetary Health, 3, 26–39.

Fold N.R., Allison M.R., Wood B.C., Thao P.T.B., Bonnet S., Garivait S., Kamens R., Pengjan S., 2020, An Assessment of Annual Mortality Attributable to Ambient $PM_{2.5}$ in Bangkok, Thailand, International Journal of Environmental Research and Public Health, 17(19), 7298.

Mostafanezhad M., Evrard O., 2020, Chronopolitics of crisis: A historical political ecology of seasonal air pollution in northern Thailand, Geoforum, 124, 400-408.

Pothirat C., Chaiwong W., Liwsrisakun C., Bumroongkit C., Deesomchok A., Theerakittikul T., Limsukon A., Tajarernmuang P., Phetsuk N., 2019a, Acute effects of air pollutants on daily mortality and hospitalizations due to cardiovascular and respiratory diseases, Journal of Thoracic Disease, 11(7), 3070-3083.

Pothirat C., Chaiwong W., Liwsrisakun C., Bumroongkit C., Deesomchok A., Theerakittikul T., Limsukon A., Tajarernmuang P., Phetsuk N., 2019b, The short-term associations of particular matters on non-accidental mortality and causes of death in Chiang Mai, Thailand: a time series analysis study between 2016-2018, International Journal of Environmental Health Research, 31(5), 538-547.

Shen Y., Yao L., 2017, $PM_{2.5}$, Population Exposure and Economic Effects in Urban Agglomerations of China Using Ground-Based Monitoring Data, International Journal of Environmental Research and Public Health, 14(7), 716.

Yang Y., Luo L., Song C., Yin H., Yang, J., 2018, Spatiotemporal Assessment of $PM_{2.5}$-Related Economic Losses from Health Impacts during 2014-2016 in China, International Journal of Environmental Research and Public Health, 15(6), 1278.

Yu G., Wang F., Hu J., Liao Y., Liu, X., 2019, Value Assessment of Health Losses Caused by $PM_{2.5}$ in Changsha City, China, International Journal of Environmental Research and Public Health, 16(11), 2063.

Zhang P., Yu M., Tian Y., Yang Y., Shi M., Li W., 2018, Spatial-temporal Change of $PM_{2.5}$ in Z City and Influencing Factors Analysis, Chemical Engineering Transactions, 66, 547-552.