The Association Between PM$_{2.5}$ Exposure and Diabetes Mellitus Among Thai Army Personnel

Apisorn Laorattapong$^{1,2}$, Sarun Poobunjirdkul$^{1,2}$, Thanapoom Rattananupong$^2$, Wiroj Jiamjarasrangsi$^2$

$^1$Division of Occupational Medicine, Department of Outpatient Service, Phramongkutklao Hospital, Bangkok, Thailand; $^2$Department of Preventive and Social Medicine, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand

**Objectives:** This study investigated the association between baseline exposures to particulate matter with a diameter <2.5 microns (PM$_{2.5}$) and subsequent temporal changes in PM$_{2.5}$ exposure with the incidence of type 2 diabetes among Royal Thai Army personnel.

**Methods:** A retrospective cohort study was conducted using nationwide health check-up data from 21,325 Thai Army personnel between 2018 and 2021. Multilevel mixed-effects parametric survival statistics were utilized to analyze the relationship between baseline (i.e., PM$_{2.5}$-baseline) and subsequent changes (i.e., PM$_{2.5}$-change) in PM$_{2.5}$ exposure and the occurrence of type 2 diabetes. Hazard ratios (HRs) and 95% confidence intervals (CIs) were employed to assess this association while considering covariates.

**Results:** There was a significant association between both PM$_{2.5}$ baseline and PM$_{2.5}$-change and the incidence of type 2 diabetes in a dose-response manner. Compared to quartile 1, the HRs for quartiles 2 to 4 of PM$_{2.5}$-baseline were 1.11 (95% CI, 0.74 to 1.65), 1.51 (95% CI, 1.00 to 2.28), and 1.77 (95% CI, 1.07 to 2.93), respectively. Similarly, the HRs for quartiles 2 to 4 of PM$_{2.5}$-change were 1.41 (95% CI, 1.14 to 1.75), 1.43 (95% CI, 1.13 to 1.81) and 2.40 (95% CI, 1.84 to 3.14), respectively.

**Conclusions:** Our findings contribute to existing evidence regarding the association between short-term and long-term exposure to PM$_{2.5}$ and the incidence of diabetes among personnel in the Royal Thai Army.

**Key words:** Particulate matter, Air pollution, Type 2 diabetes, Military personnel

**INTRODUCTION**

Among the many environmental issues that have a negative impact on human health, air pollution is a significant concern. According to the World Health Organization (WHO), air pollution causes more than 7 million deaths per year, with over 90% of these fatalities occurring in low-income to middle-income countries, particularly in East Asia, South Asia, and the Western Pacific region [1]. Among the various air pollutants, particulate matter with a diameter <2.5 microns (PM$_{2.5}$) is considered the most harmful to human health. Evidence from both human and animal studies has suggested that PM$_{2.5}$ is a significant risk factor for type 2 diabetes [2-4], a chronic disease with a significant public health burden worldwide and a rising trend in Thailand [5,6].

Several studies have shown that an increase in PM$_{2.5}$ has a significant impact on the global burden of diabetes. According to the Global Burden of Disease (GBD) 2017 report, 2.94 million deaths were attributed to particulate matter exposure [7]. In 2019, a fifth of the global burden of type 2 diabetes was attributable to PM$_{2.5}$ exposure, with an estimated 3.78 deaths per 100,000 population and 167 disability-adjusted life-years (DALYs) per 100,000 population [8]. However, the exposure-re-
response curve in the GBD does not provide reliable estimates at the upper end of the global ambient air pollution exposure range due to a scarcity of studies in highly polluted areas. In addition, the exposure measurements in these studies were heterogeneous. Specifically, the exposure range over which risks were assessed varied, and the adjustments for potential confounders varied [8].

Most research on the relationship between PM$_{2.5}$ exposure, blood sugar levels, and incident diabetes mellitus has been conducted in developed countries such as Hong Kong [9], Japan [10], Canada [11], Denmark [12], and the United States [13]. Studies from developing countries like India [14], China [15], and Indonesia [16] are relatively scarce, with China contributing most of the available research. Because most of these studies were cross-sectional, results that shed light on causation are limited.

This study investigated the association between ambient PM$_{2.5}$ exposure and type 2 diabetes risk in Thailand. Army personnel were of particular interest due to their outdoor work and regular engagement in combat drills. A longitudinal design was utilized. Both baseline and subsequent PM$_{2.5}$ exposure were assessed, and various potential confounders were considered. Specifically, the study objective was to determine the association of both baseline PM$_{2.5}$ exposures and subsequent temporal changes in PM$_{2.5}$ exposure with the incidence of type 2 diabetes among the Royal Thai Army personnel, considering potential confounders at the individual as well as area level.

**METHODS**

**Study Population**

This retrospective cohort study was conducted within the Royal Thai Army. The study population consisted of 91,078 individuals who underwent health check-ups in 461 army units across Thailand in 2018 (Figure 1). Participants were excluded who had missing data for workplace locations (n = 3157), no data for PM$_{2.5}$ exposure from the Geo-Informatics and Space Technology Development Agency (GISTDA; n = 1212), incomplete demographic information (n = 4320), and other affiliations (n = 5907). Officers with a rank of general and above were also excluded from the study (n = 155). The study included individuals who were stationed in active duty positions, were aged 35-60 years, had at least 2 annual health checks between 2018 and 2021, and had not been diagnosed with diabetes before 2018. The study ultimately included 21,325 eligible participants.

The required sample size for this study was determined using the formula for comparing 2 incidence rates [17], with a 5% alpha error and 80% statistical power, a follow-up time of 3 years, and postulated type 2 diabetes incidence rates of 8.1 and 11.4 per 1000 person-years for those in the quintile I and quintile V exposure levels, respectively [13]. The calculated number of participants needed was 18,276. Thus, our actual number of participants was deemed sufficient to achieve adequate statistical power to address the research questions in this study.

The follow-up period between 2018 and 2021 was calculated in person-years from the date of study enrollment (2018) to the date of the participant’s last interview, or any date within

![Figure 1](thefig.png) **Figure 1.** The flow chart of study population selection. PM$_{2.5}$, particulate matter with a diameter <2.5 microns; GISTDA, Geo-Informatics and Space Technology Development Agency; DM, diabetes mellitus.
the study period that the participant reached 60 years of age, died, or developed diabetes. The onset of diabetes was considered the outcome event, and the other conditions were considered censored events. The numbers of participants with 1, 2, and 3 follow-up years were 3084 (14.5%); 12 018 (56.4%); and 6223 (29.2%).

Assessment of Diabetes

The diagnosis of diabetes or treatment for diabetes was based on the diagnostic criteria provided by the American Diabetes Association [18], which included a fasting plasma glucose (FPG) level ≥ 126 mg/dL (7.0 mmol/L) or a medical record of diabetes mellitus.

Exposure Assessment

The data for PM$_{2.5}$ were obtained from the GISTDA of Thailand. GISTDA uses satellite data to monitor particulate matter concentrations. The agency provides an approximate average of PM$_{2.5}$ coverage across the entire country, using the Aerosol Optical Depth parameter obtained from satellites equipped with the Moderate Resolution Imaging Spectroradiometer. PM$_{2.5}$ levels were forecast and monitored at a resolution of approximately 3×3 km$^2$, with subsequent averaging at the sub-district level. Daily PM$_{2.5}$ data were used to calculate the annual average. PM$_{2.5}$ exposure was summarized in 2 parameters: (1) PM$_{2.5}$-baseline, which used the average PM$_{2.5}$ exposure from 2015 to 2017 to assess the effects of long-term exposure, and (2) PM$_{2.5}$-change, which calculated the difference between PM$_{2.5}$-baseline and the PM$_{2.5}$ levels in lag years 1-3 before an outcome event or censorship. These 2 parameters were used respectively to assess the impact of spatial (i.e., inter-cluster) and temporal (i.e., intra-cluster) variations in PM$_{2.5}$ exposure on type 2 diabetes risk. Other weather data, including rainfall, relative humidity, average wind speed, and average temperature were obtained from the Pollution Control Department, Ministry of Natural Resources and Environment. Data on other air pollutants such as sulfur dioxide (SO$_2$), nitrogen dioxide (NO$_2$), ozone (O$_3$), and carbon monoxide (CO) were obtained from the Meteorological Department and the Pollution Control Department’s application named Air4Thai [19]. The data used for this analysis covered the period between 2015 and 2017.

Covariate Data

Covariates included in the analysis were age, sex, height, weight, smoking status (never smoked, ex-smoker, non-regular smoker, regular smoker, not specified), alcohol consumption (never, ex-drinker, non-regular drinker, regular drinker, not specified), and physical activity (never, <150, >150 min/wk, not specified). Overweight was defined as having a body mass index (BMI) between 23.0 kg/m$^2$ and 24.9 kg/m$^2$, and obesity was defined as having a BMI ≥ 25.0 kg/m$^2$ [20]. These covariates were obtained from the Army Health Examination data. An answer of “not specified” in the questionnaire was considered missing information and the participant was excluded.

Statistical Analysis

In the descriptive analysis, participants were categorized into 4 groups according to the baseline PM$_{2.5}$ exposure level. Qualitative data, including sex, smoking status, alcohol consumption, and physical activity were presented using frequency and percentage. Quantitative data (e.g., age; BMI; annual average PM$_{2.5}$ exposure; and FPG, SO$_2$, NO$_2$, CO, and O$_3$ levels) were presented using mean and standard deviation (SD) or median and interquartile range, depending on the distribution of data. Differences in demographic characteristics and confounding factors among the participant groups were determined by the chi-square test for qualitative data, and by the one-way analysis of variance or Kruskal-Wallis tests for quantitative data, depending on the distribution of the data. The incidence of diabetes was calculated by dividing the number of new-onset diabetes cases by the total time at risk of diabetes in person-years and presented as an incidence rate per 1000 person-years.

Inferential analysis was conducted using multilevel mixed-effects parametric survival analysis (Weibull distribution) to analyze the relationships of PM$_{2.5}$-baseline and PM$_{2.5}$-change with the incidence of diabetes [21]. The level 1 variables included individual-level factors such as age, sex, BMI, blood sugar level, smoking status, alcohol consumption, and exercise status. The level 2 variables were area-level (or army-unit) factors, including PM$_{2.5}$ exposure level, rainfall amount, relative humidity, average wind speed, and average temperature, as well as SO$_2$, NO$_2$, CO, and O$_3$ levels. Hazard ratios (HRs) and the corresponding 95% confidence intervals (CIs) were calculated and presented as the measure of association.

The exposure-outcome associations were analyzed with 4 models. In the first 3 models, either PM$_{2.5}$-baseline or PM$_{2.5}$-change parameters were analyzed separately as a sole predictor while, in the fourth model, both PM$_{2.5}$-baseline and PM$_{2.5}$-change parameters were simultaneously included as the pre-
2.5 was divided into 4 quartiles and the first quartile was used as a reference value. Model I was the crude model where either PM$_{2.5}$-baseline or PM$_{2.5}$-change parameters were included as the sole predictor. In model II, the individual-level covariates, including age, sex, BMI, baseline plasma glucose level, smoking status, alcohol consumption, and physical activity level were added to model I. In model III, area-level covariates such as relative humidity, wind speed, and rainfall were added to model II. Model IV was similar to model III except that both PM$_{2.5}$-baseline and PM$_{2.5}$-change parameters were included as the 2 main predictors. Multicollinearity was solved by including independent variables with a pairwise correlation <70% the statistical models [22].

The statistical analysis was conducted using Stata version 17.0 (StataCorp., College Station, TX, USA), and a 2-tailed p-value <0.05 indicated statistical significance.

**Ethics Statement**

The study was approved by the Research Ethics Review Committee, Faculty of Medicine, Chulalongkorn University (IRB reference No. 0882/65) and the Institutional Review Board of the Royal Thai Army Medical Department (IRB reference No. 0954/2566).

**RESULTS**

**Participant Characteristics**

The participants ranged in age from 35 years to 60 years, with a mean ± SD age of 46.2 ± 7.3 years. The number of male participants was 17,994 (84.4%). The mean ± SD BMI was 24.57 ± 3.44 kg/m². Most participants never smoked (57.5%), were non-regular drinkers (53.5%), and engaged in physical activity for more than 150 min/wk (59.0%). When categorizing the participants into PM$_{2.5}$-baseline quartiles (Table 1), significant group differences were observed in the composition of age, sex, smoking status, alcohol consumption, and exercise status. However, no significant group differences were observed in BMI.

**Particulate Matter With a Diameter <2.5 Microns Exposure**

The average annual PM$_{2.5}$ exposure from 2015 to 2017 (PM$_{2.5}$-baseline) for the 461 army units across Thailand ranged from 14.64 µg/m³ to 25.16 µg/m³, with a median of 21.64 µg/m³ (quartiles 1-3, 19.17-24.38). The temporal change of PM$_{2.5}$ levels in the lag years 1-3 (PM$_{2.5}$-change) from 2018 to 2020 ranged from -5.86 µg/m³ to 6.06 µg/m³, with a mean ± SD of 0.22 ± 1.41 µg/m³. The distributions of PM$_{2.5}$-baseline and PM$_{2.5}$-change, according to their quartiles, are shown in Supplementary Material 1A and B, respectively.

**Association Between Particulate Matter With a Diameter <2.5 Microns Exposure and the Incidence of Type 2 Diabetes**

The incidence rate of diabetes mellitus tended to fluctuate in relation to increasing PM$_{2.5}$ concentrations: the incidence rates in PM$_{2.5}$ quartiles 1-4 were 21.87, 25.47, 23.07, and 18.13 per 1000 person-years, respectively (Table 2).

This study analyzed the relationship between the spatial and temporal variations in PM$_{2.5}$ exposure (in terms of PM$_{2.5}$-baseline and PM$_{2.5}$-change) with the incidence of type 2 diabetes. A significant association between PM$_{2.5}$-baseline and the increased incidence of type 2 diabetes was observed only in the fully adjusted models (models III and IV). For model IV, the HR (95% CI) for quartiles 2-4 compared to quartile 1 of PM$_{2.5}$-baseline were 1.11 (95% CI, 0.74 to 1.65), 1.51 (95% CI, 1.00 to 2.38), and 1.77 (95% CI, 1.07 to 2.93), respectively. In contrast, PM$_{2.5}$-change was found to be significantly associated with the disease risk with a consistent dose-response pattern all the way from the crude (model I) to the fully adjusted model (model IV), though the magnitudes of association were generally reduced. The HRs (95% CI) for quartiles 2-4 compared to quartile 1 of PM$_{2.5}$-change were 1.36 (95% CI, 1.11 to 1.65), 1.97 (95% CI, 1.61 to 2.42), and 3.67 (95% CI, 2.99 to 4.51) for model I and 1.41 (95% CI, 1.14 to 1.75), 1.43 (95% CI, 1.13 to 1.81), and 2.40 (95% CI, 1.84 to 3.14) for model IV, respectively (Table 3).

Since the PM$_{2.5}$-change category was difficult to interpret, we reclassified it into 7 categories and reanalyzed model IV by designating the middle category (with a temporal change magnitude between -0.5 and 0.5 µg/m³) as the reference category; these results are shown in Figure 2. The increasing categories of PM$_{2.5}$-change were significantly associated with an increased incidence of type 2 diabetes in a progressive manner. For the PM$_{2.5}$-change categories of 0.51 µg/m³ to 1.50 µg/m³, 1.51 µg/m³ to 2.50 µg/m³, and greater than 2.50 µg/m³, the HRs (95% CIs) were: 1.51 (95% CI, 1.24 to 1.84), 3.99 (95% CI, 3.04 to 5.25), and 4.91 (95% CI, 3.33 to 7.23), respectively. In contrast, decreasing categories of PM$_{2.5}$-change were not significantly associated with a decrease in the incidence of type 2 diabetes.
DISCUSSION

In this study, we investigated the relationship of spatial and temporal variations in PM$_{2.5}$ exposure (based on PM$_{2.5}$-baseline and PM$_{2.5}$-change) with the incidence of type 2 diabetes among Thai Army personnel from 2018 to 2021. While both PM$_{2.5}$ parameters were significantly associated with type 2 diabetes incidence, those for temporal variation in PM$_{2.5}$ exposure were
Table 3. Hazard ratios for the association of baseline PM$_{2.5}$ exposure and changes in PM$_{2.5}$ exposure over 3 years with the incidence of type 2 diabetes among Thai Army personnel (n = 21325)$^1$

<table>
<thead>
<tr>
<th>PM$_{2.5}$ parameter (Min. Max, µg/m$^3$)</th>
<th>Model I</th>
<th>Model II</th>
<th>Model III</th>
<th>Model IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$-baseline$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartile 1 (14.64, 19.17)</td>
<td>1.00 (reference)</td>
<td>1.00 (reference)</td>
<td>1.00 (reference)</td>
<td>1.00 (reference)</td>
</tr>
<tr>
<td>Quartile 2 (19.18, 21.64)</td>
<td>1.16 (0.86, 1.58)</td>
<td>1.17 (0.87, 1.56)</td>
<td>1.16 (0.79, 1.70)</td>
<td>1.11 (0.74, 1.65)</td>
</tr>
<tr>
<td>Quartile 3 (21.65, 24.37)</td>
<td>1.24 (0.89, 1.70)</td>
<td>1.24 (0.91, 1.69)</td>
<td>1.37 (0.92, 2.03)</td>
<td>1.51 (1.00, 2.28)*</td>
</tr>
<tr>
<td>Quartile 4 (24.38, 25.16)</td>
<td>0.85 (0.55, 1.19)</td>
<td>0.85 (0.59, 1.23)</td>
<td>2.01 (1.23, 3.27)**</td>
<td>1.77 (1.07, 2.93)*</td>
</tr>
<tr>
<td>PM$_{2.5}$-change$^2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartile 1 (-5.86, -0.65)</td>
<td>1.00 (reference)</td>
<td>1.00 (reference)</td>
<td>1.00 (reference)</td>
<td>1.00 (reference)</td>
</tr>
<tr>
<td>Quartile 2 (-0.64, -0.30)</td>
<td>1.36 (1.11, 1.65)**</td>
<td>1.30 (1.07, 1.58)**</td>
<td>1.39 (1.12, 1.71)**</td>
<td>1.41 (1.14, 1.75)**</td>
</tr>
<tr>
<td>Quartile 3 (0.31, 1.02)</td>
<td>1.97 (1.61, 2.42)***</td>
<td>1.92 (1.57, 2.36)***</td>
<td>1.44 (1.14, 1.81)**</td>
<td>1.43 (1.13, 1.81)**</td>
</tr>
<tr>
<td>Quartile 4 (1.03, 6.06)</td>
<td>3.67 (2.99, 4.51)***</td>
<td>3.48 (2.83, 4.29)***</td>
<td>2.40 (1.84, 3.13)***</td>
<td>2.40 (1.84, 3.14)***</td>
</tr>
</tbody>
</table>

Values are presented as hazard ratio (95% confidence interval). PM$_{2.5}$, particulate matter with a diameter < 2.5 microns; Min, minimum; Max, maximum.

$^1$Model I: only PM$_{2.5}$-baseline or PM$_{2.5}$-change was included as a predictor; Model II: Model I plus individual-level covariates (such as age, sex, BMI, baseline plasma glucose level, smoking status, alcohol consumption, and physical activity); Model III: Model II plus area-level covariates (such as relative humidity, wind speed, and rainfall); Model IV: both PM$_{2.5}$-baseline and PM$_{2.5}$-change were simultaneously included as the predictors, plus individual-level and area-level covariates.

$^2$The difference between the baseline PM$_{2.5}$ and the PM$_{2.5}$ levels in lag years 1-3 before the outcome event or censorship.

$^3$p$<0.05; **p$<0.01; ***p$<0.001.

Figure 2. Hazard ratios for relationship between the different levels of PM$_{2.5}$ change and risk of type 2 diabetes (the middle category (PM$_{2.5}$ change of -0.50 to 0.50 µg/m$^3$) was designated as the reference). Bar represents the hazard ratio and range represents the corresponding 95% confidence interval. Numbers in parentheses represents the number of participants in each category.

More robust than those for spatial variation. While the temporal increase in PM$_{2.5}$ exposure was significantly and progressively associated with type 2 diabetes risk, a decrease in PM$_{2.5}$ exposure did not decrease disease risk.

We found that higher exposures to PM$_{2.5}$ were associated with an increased risk of diabetes, and the strength of association was proportional to the amount of PM$_{2.5}$. These results are consistent with previous studies, such as those conducted by Liu et al. [15], Li et al. [23] in China and Lee et al. [10] in Japan. However, 2 studies by Curto et al. [14] in India and Coogan et al. [13] in the United States did not find such a relationship. The variation in findings could be attributed to several factors, including the heterogeneity of population characteristics, opportunities for exposure, toxicological properties of PM$_{2.5}$, or other factors related to diabetes such as the eating habits in different study areas.

Furthermore, our finding that the temporal change had a more pronounced impact than the spatial difference of PM$_{2.5}$ exposure on type 2 diabetes risk may reflect the shorter time frame between the increased PM$_{2.5}$ exposure and changes in FPG. The findings of Zhan et al. [24] and Cai et al. [25] indicated that short-term and medium-term exposure to ambient PM$_{2.5}$ was associated with higher FPG levels. These consistent results across studies suggest that short-term and medium-term exposure to PM$_{2.5}$ may contribute to increased FPG levels. However, other alternative explanations are also possible. More studies are therefore needed.

The magnitudes of association between PM$_{2.5}$ exposure and diabetes risk reported in our study were noteworthy and generally stronger than those reported previously. When the HR
for PM$_{2.5}$-change and diabetes incidence in Table 3 was reanalyzed per 1 µg/m$^3$ increase rather than by quartile comparison, the HR (95% CI) was 1.38 (95% CI, 1.27 to 1.50), as compared to the hazard, risk, or odds ratios of 0.95 to 1.25 in previous reports [10,26,27]. This might be because the individuals in our study population had military occupations that primarily involved outdoor duties, thus were exposed to higher levels of PM$_{2.5}$ than the general population. In addition, we observed variations between the PM$_{2.5}$ data collected from satellites (maximum 25.53, minimum 13.59, and average 20.77 µg/m$^3$) and the PM$_{2.5}$ data obtained from field stations (maximum 33.30, minimum 14.52, and average 22.76 µg/m$^3$) (results not shown). Notably, the range of PM$_{2.5}$ values from the field stations was broader than the range observed from satellite data, which suggests that the HR values in this study may be overestimated.

The strengths of our study included the use of a cohort design to investigate the relationship between PM$_{2.5}$ exposure and diabetes. We also considered various potential confounders, both at individual and sub-district levels. Our study also analyzed both the temporal variation and spatial variation associated with PM$_{2.5}$. However, limitations of the study included a lack of individual data on eating behaviors [28] and family history [29] related to diabetes. In addition, we did not conduct hemoglobin A1c tests, which are commonly used for the diagnosis of diabetes. Our participants were soldiers, who may have different eating habits, exercise routines, and exposure levels to PM$_{2.5}$ compared to the general population. Furthermore, the overlap of the coronavirus disease 2019 (COVID-19) pandemic with our study period, with its resultant disruption in social, economic, and physical environments as well as individual daily life behaviors [30,31], might have confounded our study findings. During our study period, we observed that the pandemic had an impact on PM$_{2.5}$ levels from transportation-related sources. However, these sources were approximately 13% of all PM$_{2.5}$ sources [32,33]. Meanwhile, there were other significant sources of PM$_{2.5}$, such as open burning and manufacturing industries that continued their operations by implementing “bubble and seal” control policies [34]. The impact of the pandemic on individuals’ daily-life behaviors, such as wearing masks and decreasing outdoor physical activity [35], might have resulted in less exposure to PM$_{2.5}$ than our exposure assessments (based on the ambient PM$_{2.5}$ monitoring data) reflect. However, this exposure measurement error was most likely either non-differential or differential toward the areas and periods with poorer air quality (i.e., air pollution levels relate positively with mask-wearing [36] and inversely with outdoor physical activity levels [37]). This would result in weakening rather than overestimating the magnitude of the exposure-outcome association [38]. Nevertheless, the impact of the COVID-19 pandemic was extensive and could not be considered completely; further studies during a normal period are needed to confirm or refute our findings.

**SUPPLEMENTAL MATERIALS**

Supplemental material is available at https://doi.org/10.3961/jpmph.23.292.

**CONFLICT OF INTEREST**

The authors have no conflicts of interest associated with the material presented in this paper.

**FUNDING**

None.

**ACKNOWLEDGEMENTS**

All authors would like to thank: Air4Thai of the Pollution Control Department, the Ministry of Natural Resources and Environment, Thailand; the Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand; and the Royal Thai Army Medical Department for providing the environmental and health data used in this study.

**AUTHOR CONTRIBUTIONS**

ORCID

Apisorn Laorattapong  https://orcid.org/0009-0000-7454-9934
Sarun Poobunijirdkul  https://orcid.org/0009-0001-4274-5663
Thanapoom Rattananupong  https://orcid.org/0000-0002-3853-1785
Wiroj Jiamjarasrangsi  https://orcid.org/0000-0002-0610-6848

REFERENCES


22. Leiby BD, Ahner DK. Multicollinearity applied stepwise stochastic imputation: a large dataset imputation through correlation-
PM2.5 and Type 2 Diabetes in the Thai Army


