The Concentration of Fine Particulate Matter from Antique Handmade Brick Kilns in Chiang Mai, Thailand

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ABSTRACT

Air quality assessment in particulate matter with a size of less than 2.5 microns ($PM_{2.5}$) is essential because it affects urban residential health. Hence, this research studied the analysis of $PM_{2.5}$ value from antique Mon handmade stove house usage in Chiang Mai, using the AERMOD air quality dispersion model. The data for the modeling was collected from a survey regarding the amounts of production and fuel, and the location of the brick kilns used to calculate the amount of air pollution emissions. The summarized values were the emission factor, the climate data as the surface meteorological data, the upper-air meteorological data obtained from the National Oceanic and Atmospheric Administration, and national geographic data. The Albedo and Bowen ratios and the surface roughness values were identified using satellite data and then presented in a map of the dust intensity distribution. The results found that the highest value of $PM_{2.5}$ concentration at the smoke point was 209.19 µg/m^3, while the average values were 48.21 µg/m^3. The $PM_{2.5}$ concentration at the stack pointer was higher than the standard scores of Thai and World Health Organization (WHO) general atmospheric air quality standards. However emissions varied, and average $PM_{2.5}$ concentrations exceeded WHO standards and, in the case of full operation, exceeded Thai standards, posing health risks.

Keywords: $PM_{2.5}$, AERMOD, air pollution modeling, urban pollution, brick kilns, health impact, Chiang Mai

INTRODUCTION

Nowadays, particulate matter (PM) is a key problem in Chiang Mai that affects residents' health yearly. The major reasons causing the dust are wildfires and smoke from vehicles and industrial factories (Srinamphon et al., 2022). Therefore, the city has been covered with particulate matter with a size of or less than 10 to 2.5 microns. These particulate matter, specifically 10 microns (PM_{10}) and particulate matter 2.5 microns ($PM_{2.5}$), are used to calculate the air quality index (AQI) (K & Kumar, 2022). The particulate matter emission from the antique "Mon" handmade brick kilns is difficult to avoid due to its unique method and procedure that has been inherited for a long time (Bhat & Gaga, 2022; Saju et al., 2020). It has also been a source of local tradition and a famous product from Chiang Mai. The production of "Mon" bricks has been reduced due to the long duration of production (around one month), which is much longer than other brick productions. However, some local people want to preserve this method as a heritage for the next generations. The bricks are made from clay that mixes with sand or sandy clay with some ashes before passing through the block mold. Then, the raw bricks are put under the sun for 3-10 days before being baked at a high temperature of 900-1000 degrees Celsius (°C) for 12 hours. Then, the brick is cooled down for another 12 hours. The production methods need to use dirty solid fuels such as logs and woodchips to produce the bricks at a high temperature of 900-1,000°C for 12 hours, causing high emissions that affect the local environment and local people's health (Bungadaeng et al., 2019; Chatreejansakul, 2002; Onchang & Hemwat, 2016; Sahaya Sakila & Manohar, 2024). Thus, it is necessary to study the effects of the kilns to find a suitable solution to minimize the impacts. In contrast, previous studies have assessed urban $PM_{2.5}$ sources, but few have focused on emissions from heritage-based kilns like those in Chiang Mai. This study used air quality dispersion modeling to assess the impact of kiln emissions (Limpasanticharoen et al., 2018; Pongprueksa & Chatchupong, 2016). The American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) was established to introduce state-of-the-art modeling concepts into the air quality models of the United States Environmental Protection Agency, known as the American Meteorological Society-Environmental Protection Agency Regulatory Model (AERMOD) (Rzeszutek & Szulecka, 2021).

LITERATURE REVIEW

Antique "Mon" handmade brick kilns

The production of aged Mon-Lanna handmade bricks was developed by using a tool to produce bricks instead of molding them by hand. The tool can provide more pressure than a hand can by compressing much more firmly and producing greater quantities. Unfortunately, Mon brick production has been reduced due to the production duration taking approximately a month, which is longer than other production methods (Prommuang et al., 2024b). However, local people still keep this career because they need to preserve this local knowledge as a heritage for their children. People living near brick kilns had consistently worse lung function, respiratory symptoms, musculoskeletal complaints, and inflammation (Nicolaou et al., 2024). The first step in production is the transferring of the clay into the field, which consists of the following steps: (1) the clay preparation starts by selecting the clay that mixes with sand or sandy clay, (2) the prepared clay is left in a pond for 2-3 days for a better combination, (3) the clay is added with some ash into the briquette machine. In the past, stomping mixed the husk with clay instead of ash. The clay is passed through the block mold into a thick bar in the rack to be cut into bricks and placed on the tiles later, (4) the raw bricks are left under the sun directly for 3-10 days to allow them to dry, which turns the colour to be off-white. The duration is dependent on the season or how strong the sun is, (5) the off-white bricks are baked with a high heat of biofuels, such as logs or woodchips, at a temperature of around 900-1000 °C for 12 hours and left to cool down for approximately another 12 hours, and (6) the bricks are removed from the stove houses to lower the temperature and cool down. The best quality brick must have an orange-brick color throughout the whole brick, a smooth surface without any bumps at the

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corners, and no cracks and resonates after being knocked. Generally, the produced bricks are 4 inches in height, 6 inches in length inches, and 8 inches wide. The production quantities mainly depend on market demand, and biofuels are dependent on the supply of each family and agricultural section in each season. Usually, logs and woodchips from bamboo, Monkey Pod, Leucaena leucocephala, which is commonly named river tamarind, as well as any available woodchips, are used as the fuels for baking the bricks (Prommuang et al., 2024a). The emission factor is the index that relates to the type of fuel and can be used in the assessment of air pollution caused by many resources (Saha et al., 2020); therefore, the emission factor has been evaluated by varieties of biomass to compare with the value of air pollution, which the primary particles' resources cause (Nicolaou et al., 2024). The principle relevant to the emission factor measurement has been classified and used for the explanation of the environment, random sampling (simple or systematic), and types of burning biomass (agriculture, farm, forest, and animals' droppings) (Asif et al., 2021). By referring to the article of Simone Simões Amaral and his group (Simões Amaral et al., 2016), the value of the emission coefficient caused by the combustion of fuels from any available woodchips is related to the value of total suspended particulate (TSP). As a result, PM_{10} and tiny particles or droplets in the air that are two and one-half microns or less in width were calculated to find the intensity of the aforementioned particulate matter.

Overview PM

PM is a tiny particle in the air that includes dust, dirt, smoke, and aerosols that can float in the air for a long time. Some particles are big or dark enough to be seen as smoke, while others are so small but unique to be detected by a microscope. The electrons of PM_{10} can cause harm to people's health since they can be collected in the respiratory system if they are inhaled. Additionally, $PM_{2.5}$ is believed to cause the most risk to one's health since they have a small size of approximately one of three equal parts of the average width of a human hair. Therefore, they can reach into the inner lungs after inhaling, which is very dangerous for the inspiratory system. For more details, Thailand's 24-hour air quality standard should have $PM_{2.5}$ and PM_{10} not more than 37.5 and 120 micrograms per cubic meter ($\mu g/m^3$) in order. However, the standard of the World Health Organization (WHO) is not more than 25 and 50 $\mu g/m^3$, and the standard of the United States Environmental Protection Agency (USEPA) is not more than 35 and 150 $\mu g/m^3$, respectively. Furthermore, AQI has been used to report air quality information, which is easy for general people to understand (Horn & Dasgupta, 2024; Tan et al., 2021). Moreover, it has been used to inform the public to acknowledge the air pollution situation in each area, at which level, and whether it can affect your health or not. The air quality index is the international standard used in many countries, for example, the United States of America (USA), Australia, Singapore, Malaysia, and Thailand (Aguado & Oh, 2021). In addition, the air quality index that has been used in Thailand is calculated by comparing it with the air quality standard of the atmosphere.

Air Quality Modeling

The air quality modeling that has been widely used in AERMOD is a tool that provides mathematical forecasting analysis for the explanation of the air polluted mass' diffusion or dispersion in different conditions and for the estimation of the air polluted mass' intensity in the atmosphere that any resources have released (Park, 2024; Phetrawech & Thepanondh, 2017; Roy et al., 2016). The AERMOD program was developed in 1991 by USEPA, the United States Environmental Protection Agency, which assigned it as the preferred regulatory model. Therefore, the air quality modeling or AERMOD imagines that the atmosphere, unaffected by heat convection, will be affected by the stable boundary layer (SBL) and have the Gaussian intensity spread both vertically and horizontally. In contrast, in the atmosphere, the air is from the mass movement that occurs by the convective boundary layer (CBL) and has the Gaussian intensity spread in the horizon but has the Bi-Gaussian intensity spread vertically (Shukla et al., 2022). However, the AERMOD is the mathematical modeling used to evaluate the air pollution spread, which needs to have the spatial study data from the American Meteorological Society-Environmental Protection Agency Regulatory Model Terrain Pre-Processor

(AERMEP) and the meteorological data from the American Meteorological Society-Environmental Protection Agency Regulatory Model Meteorological Preprocessor (AERMET) (Rzeszutek & Szulecka, 2021), as presented in the following Figure 1.

Figure 1

The Structure of the Modeling System: AERMOD
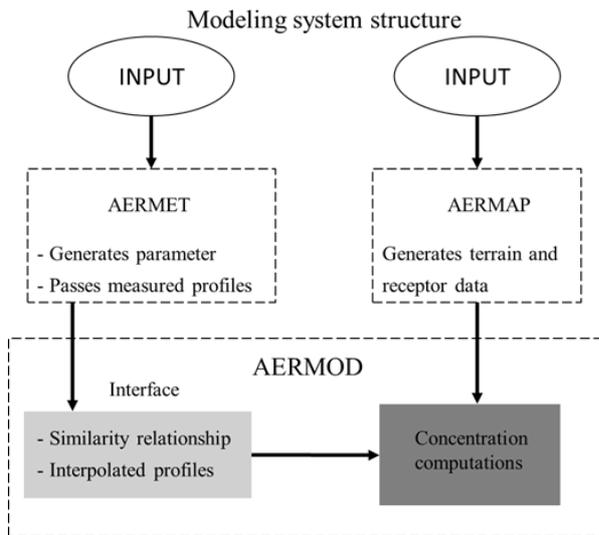
AERMAP is the model used in assigning the study area and preparing the high-low data of each research field. Therefore, the abovementioned information affects the plume's movement after touching the surface. In contrast, the AERMET is the model used for calculating the meteorological variables and formatting the data for input to the AERMOD. The data for input to the AERMET is sorted into two parts, namely the meteorological data and the surface data, which are as follows: (1) Meteorological data can be separated into two parts: surface meteorological data and upper-air meteorological data, and (2) Surface data is the surface roughness length value, the Bowen Ratio Value, and the Albedo Value for evaluating land usage. The Albedo Value is the value of solar radiation sent to space without any absorbance. The Bowen Ratio is the index value of the heat transfer for a surface that has moisture, which is the ratio of the sensible heat flux to the latent heat flux. Surface roughness length is the height at the average wind speed on the horizon equal to zero. Regarding the land usage consideration, it was classified seasonally by the standard of the land cover classification scheme of National Land Cover Dataset 1992 (NLCD92) 21-Land Cover Classification System (Faminskaya, 2020), according to the manual of AERSURFACE User's Guide Appendix A. This is mentioned in the following Table 1, which displays the grouping of ground covers for the analysis of the surface roughness length value, the Bowen Ratio Value, and the Albedo Value (Leetongin et al., 2022; Wanitchayapaisit et al., 2022; Wattanachai et al., 2021).

Table 1

NLCD 92 Land Cover Class Definitions

NLCD 92 Land Cover Class Definitions	
Main classes	**Sub-classes**
Water	11 Open Water 12 Perennial Ice/Snow
Developed	21 Low-Intensity Residential 22 High-Intensity Residential 23 Commercial/Industrial/Transportation
Barren Land	31 Bare Rock/Sand/Clay 32 Quarries/Strip Mines/Gravel Pits 33 Transitional
Forested Upland	41 Deciduous Forest 42 Evergreen Forest 43 Mixed Forest

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Table 1 (Continued)

NLCD 92 Land Cover Class Definitions	
Main classes	**Sub-classes**
Shrubland	51 Shrubland
Non-Natural Woody	61 Orchards/Vineyards/Other
Herbaceous Upland Natural/Semi-natural Vegetation	71 Grasslands/Herbaceous
Herbaceous Planted/Cultivated	81 Pasture/Hay 82 Row Crops 83 Small Grains 84 Fallow 85 Urban/Recreational grasses
Wetlands	91 Woody Wetlands 92 Emergent Herbaceous Wetlands

RESEARCH METHOD

There were three main steps in assessing the PM$_{2.5}$ concentration from the antique "Mon" handmade brick kilns production in Chiang Mai. The three steps include the survey and data collection, the evaluation of air pollution from the antique "Mon" handmade brick kilns production, and the PM analysis, as presented in Figure 2.

Survey and Data Collection

The survey was conducted to collect two types of data, which were: (1) fuel use and the productivity of the kilns, and (2) the surface and upper-air data from the National Oceanic Atmospheric Administration (NOAA) station at Chiang Mai International Airport (WMO Station ID: 48327) and the aerial photographs for the geographical analysis of the Albedo and Bowen ratios, and the surface roughness as per the NLCD1992 (Ramirez, 2021). This study focused on the dry summer season. The data collection was conducted in the dry season of January 2020, specifically focusing on January 30, 2020, when 21 kilns were in operation. Future research should explore seasonal variability in emissions and dispersion.

Emission Estimation of the Antique "Mon" Handmade Brick Kilns

Emission factors (EF) were adopted from compacted forest biomass combustion studies (Simões Amaral et al., 2016), assuming an average EF of 0.25 g/kg of fuel burned. Moreover, the coefficient of emission is not only a measurement of the emission factor to the actually burned dry fuels kilogram in a unit gram of PM2.5 emitted per kilogram of fuel (g/kg), but also the function of the energy that has been produced by the ignition in unit milligram per megajoule (mg/MJ), which was converted to the Low Heat Value (LHV) unit of burning fuels.

Estimation of Particle Matter Concentration from Kilns Activities

The airborne dust outpouring assessment used the AERMOD Model input by (1) National geographic data, (2) Weather data, and (3) Air pollution emission data. In this study, the national geographic data was the surface data, and the weather data was the meteorological data. Additionally, both data were added into the AERMET, a function subprogram by the formats of the surface meteorological data, the upper-air meteorological data, and the surface roughness

length value, the Bowen Ratio Value, and the Albedo Value to find the parameter for the AERMOD Model. Finally, the evaluated data of air pollution emission by the stove house usage was added into the AERMOD Model along with the parameter value that was the output of the AERMET Model to analyze the spreading of $PM_{2.5}$ intensity at the point of air pollution emission area.

RESULTS AND DISCUSSION

Survey Results of the Current Brick Kilns Location

The community of the antique "Mon" handmade brick kilns is located in village Number (No.) 7, Suthep Subdistrict, Muang District, Chiang Mai Province, which consists of 28 kilns in total, as presented in Figure 3. According to the data on fuel use and production in Table 2, only 21 kilns were operated during the survey period. Therefore, the modeling was divided into two

approaches: the modeling of productions from 28 and 21 kilns to compare the effects on the level of $PM_{2.5}$ under maximum and current operational capacities. While 28 kilns represent full potential use, only 21 were active during the study period, making this a comparative analysis of real vs maximum impact.
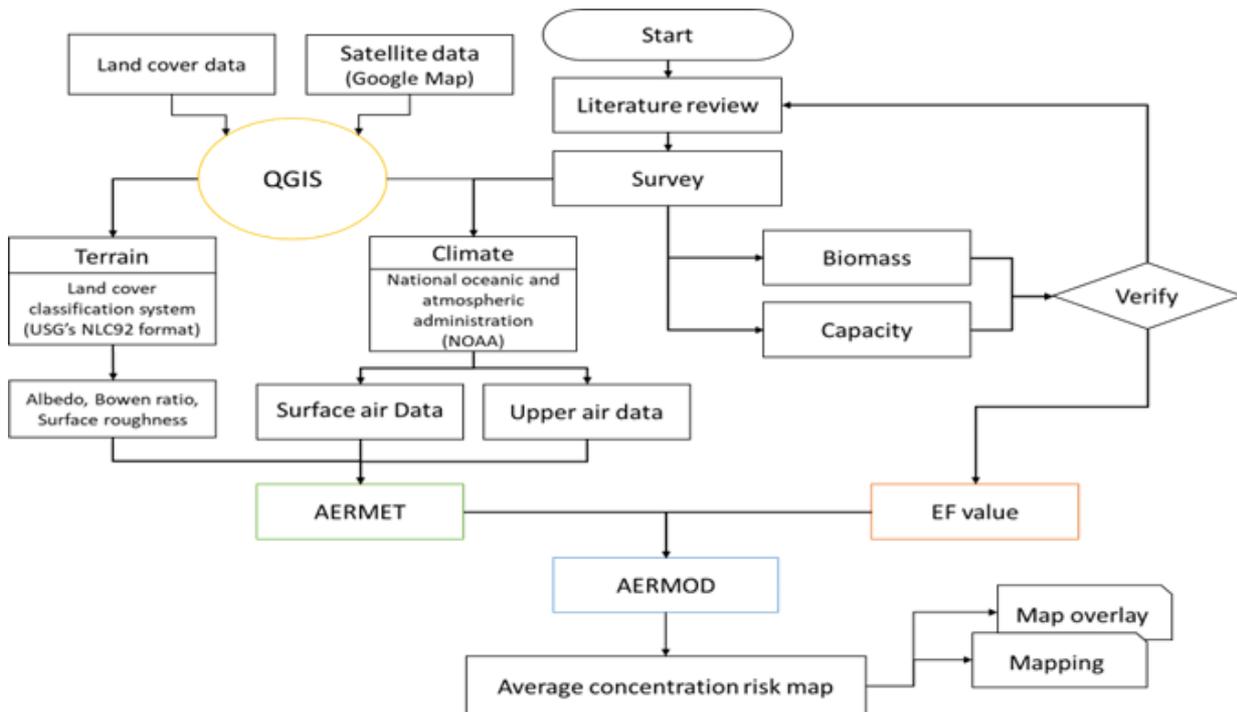
Emission Estimation

The fuels and production of 28 classical Mon brick kilns were analyzed to estimate emission rates, as presented in Table 2.

Table 2 provides the emission of all 28 ancient Mon kilns, while the modeling from January 30, 2020, uses the data from 21 kilns only (No.1 to No. 21). Maximum fuel use values were based on the highest operational estimates reported by kiln operators; not all kiln operators operated at full capacity during the survey period. Data was collected during one operational cycle per kiln in January 2020. Incorporating mean, standard deviation, and min-max values across multiple cycles is recommended for future studies.

Figure 2

Research Method Plan

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Concentration of particulate matter from kiln operation

The calculation of the Albedo Value, Bowen Ratio Value, and surface roughness value in the study area, as mentioned in Table 3, was calculated from the area divided into eight sectors, as presented in Figure 4, and the space usage condition of NLCD1992. In this study, six land covers in the sub-classes, as shown in Figure 5, were selected to be used in the mathematical forecast modeling and air quality forecast analysis by the AERMOD Program. The $PM_{2.5}$ concentration is shown in Figure 6.

Figure 3

Locations of the Classical Handmade "Mon" brick Kilns
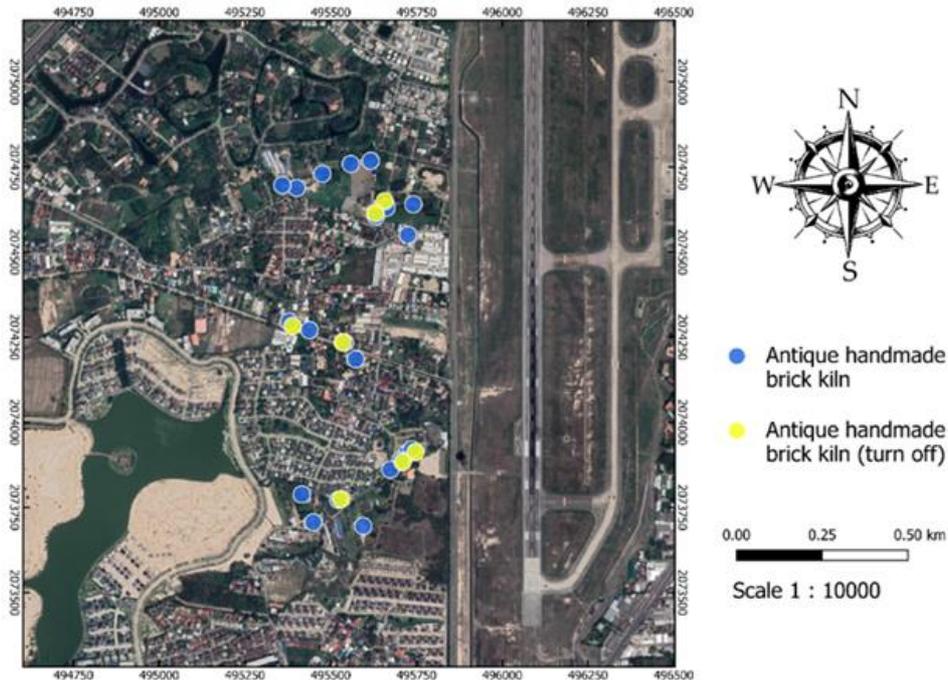
Note. Adapted from *Locations of the Classical Handmade "Mon" brick Kilns,* by Google Map, 2025 (https://www.google.co.th/maps/@18.7603388,98.9547671,16z?entry=ttu&g_ep=EgoyMDI1MDQyMy4 wIKXMDSoASAFQAw%3D%3D). Copyright 2025 by Google LLC.

Table 2

The Details of Brick Kilns' Size Fuel Usage and the Emission Rate

Kiln No.	Stack			Kiln Capacity (pcs. / time)		Productivity (pcs. / Month)	Burning Times (per month)	Max Using Fuel ß		$PM_{2.5}$ emission (g/s)
	Type (S/O)*	Diameter (m)	Height (m)	Max	Using			(kg/h)	(kg/s)	EF** 0.25 (g/kg)
1	S	0.4 x 0.4	2.5	3,000	2,500	5,000	2	175	0.05	0.625
2	S	0.6 x 0.4	3.5	3,000	2,500	5000	2	175	0.05	0.875
3	O	3.0 x 3.0	3.0	4,000	3,000	5,000	2	117	0.03	0.750
4	S	0.4 x 0.4	2.5	3,000	2,500	5000	2	175	0.05	0.625
5	S	0.4 x 0.4	2.5	3,000	2,500	5000	2	175	0.05	0.625

Table 2 (Continued)

Kiln No.	Stack			Kiln Capacity (pcs. / time)		Productivity (pcs. / Month)	Burning Times (per month)	Max Using Fuel ß		PM$_{2.5}$ emission (g/s)
	Type (S/O)*	Diameter (m)	Height (m)	Max	Using			(kg/h)	(kg/s)	EF** 0.25 (g/kg)
6	O	3.0 x 3.0	3.0	4,000	3,000	6,000	2	117	0.03	0.750
7	O	3.0 x 3.0	2.5	4,000	3,000	5,000	2	117	0.03	0.625
8	O	3.0 x 2.5	2.0	4,000	3,000	5,000	2	175	0.05	0.500
9	O	3.0 x 2.5	3.0	10,000	8,000	32,000	4	350	0.1	0.750
10	O	3.0 x 2.5	3.0.	10,000	8,000	32,000	4	350	0.1	0.750
11	O	3.0 x 2.5	2.3	3,000	2,000	4,000	2	117	0.03	0.575
12	O	3.0 x 3.0	2.5	5,000	5,000	20,000	4	175	0.05	0.625
13	O	3.0 x 3.0	2.5	5,000	5,000	15,000	3	175	0.05	0.625
14	O	3.0 x 3.0	3.5	5,000	5,000	15,000	3	175	0.05	0.875
15	O	4.0 x 3.0	2.5	4,000	4,000	12,000	3	175	0.05	0.625
16	O	3.0 x 3.0	3.0	4,000	3,000	5,000	2	117	0.03	0.750
17	S	0.4 x 0.4	2.5	3,000	2,500	5,000	2	175	0.05	0.625
18	O	3.0 x 3.0	2.5	3,000	2,500	5,000	2	175	0.05	0.625
19	O	3.0 x 3.0	2.5	3,000	2,500	5,000	2	175	0.05	0.625
20	O	3.0 x 3.0	2.5	3,000	2,500	5,000	2	175	0.05	0.625
21	O	3.0 x 3.0	2.5	3,000	2,500	5,000	2	175	0.05	0.625
22	O	3.0 x 3.0	2.5	3,000	2,500	5,000	2	175	0.05	0.625
23	O	3.0 x 3.0	2.5	4,000	4,000	8,000	2	175	0.05	0.625
24	O	3.0 x 3.0	2.5	4,000	4,000	8,000	2	233	0.06	0.625
25	O	3.0 x 3.0	2.5	4,000	4,000	8,000	2	233	0.06	0.625
26	O	3.0 x 2.5	2.5	5,000	5,000	10,000	2	233	0.06	0.625
27	O	3.0 x 3.0	2.5	4,500	4,000	8,000	2	233	0.06	0.625
28	O	3.0 x 3.0	2.5	4,000	4,000	8,000	2	233	0.06	0.625

Note. * S: shoot and O: open, ** EF values found in the literature for the compacted forest biomass burning in the combustor.

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Figure 4

The Eight Separated Sectors for the Albedo Value, the Bowen Ratio Value, and Surface Roughness Estimation
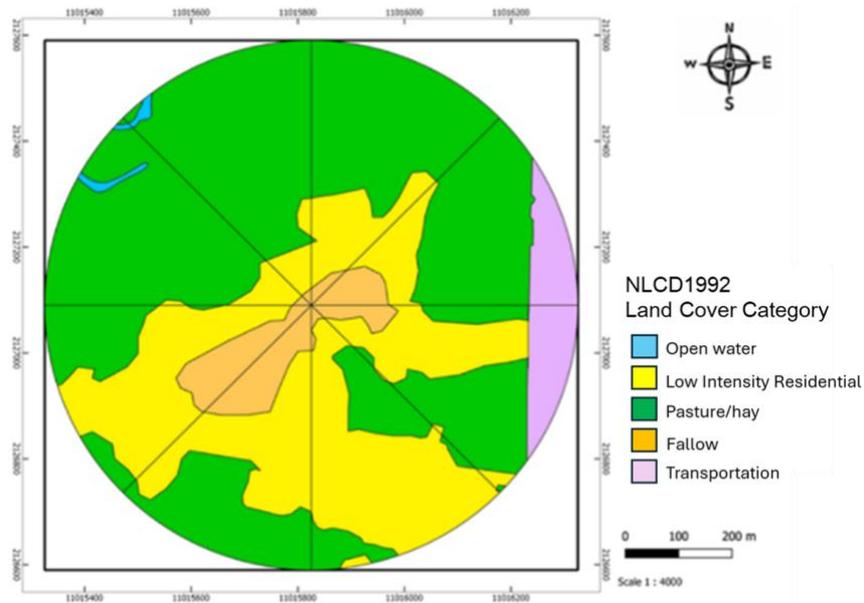

Figure 5

NLCD 92 Land Cover Class Definitions

A) 11 Open Water
B) 21 Low-Intensity Residential
C) 23 Commercial / Industrial / Transportation
D) 81 Pasture / Hay
E) 83 Small Grains
F) 84 Fallow

Note. A) Class 11 open water, B) Class 21 low-intensity residential, C) Class 23 commercial/industrial/transportation, D) Class 81 pasture/hay, E) Class 83 small grains, and F) Class 84 fallow.

Table 3

The Summary of the Albedo Value, The Bowen Ratio Value, and Surface Roughness for AERMET

Sector	Class Number* (%-Area)						AERMET		
	11 (%)	21 (%)	23 (%)	81 (%)	83 (%)	84 (%)	Albedo	Bowen Ratio	Surface Roughness
1	-	77.4	-	-	21.2	1.4	0.169	1.887	0.557
2	-	61.2	17.1	-	14.5	7.2	0.171	2.063	0.422
3	-	35.0	18.0	6.0	36.0	5.0	0.180	1.930	0.231
4	-	74.1	-	8.0	17.2	0.7	0.284	2.723	0.349
5	-	43.5	-	-	41.7	14.8	0.180	1.717	0.509
6	-	56.8	-	-	27.8	15.4	0.174	1.784	0.554
7	2.0	6.0	-	-	91.7	0.3	0.197	1.530	0.161
8	1.2	6.3	-	-	92.2	0.3	0.197	1.532	0.165

Note. Class Number 11 - Open Water, 21 - Low-Intensity Residential, 23 - Commercial/Industrial/Transportation (Site at Airport), 81 – Pasture/Hay, 83 - Small Grains, 84 – Fallow.

Figure 6

PM$_{2.5}$ Concentration,
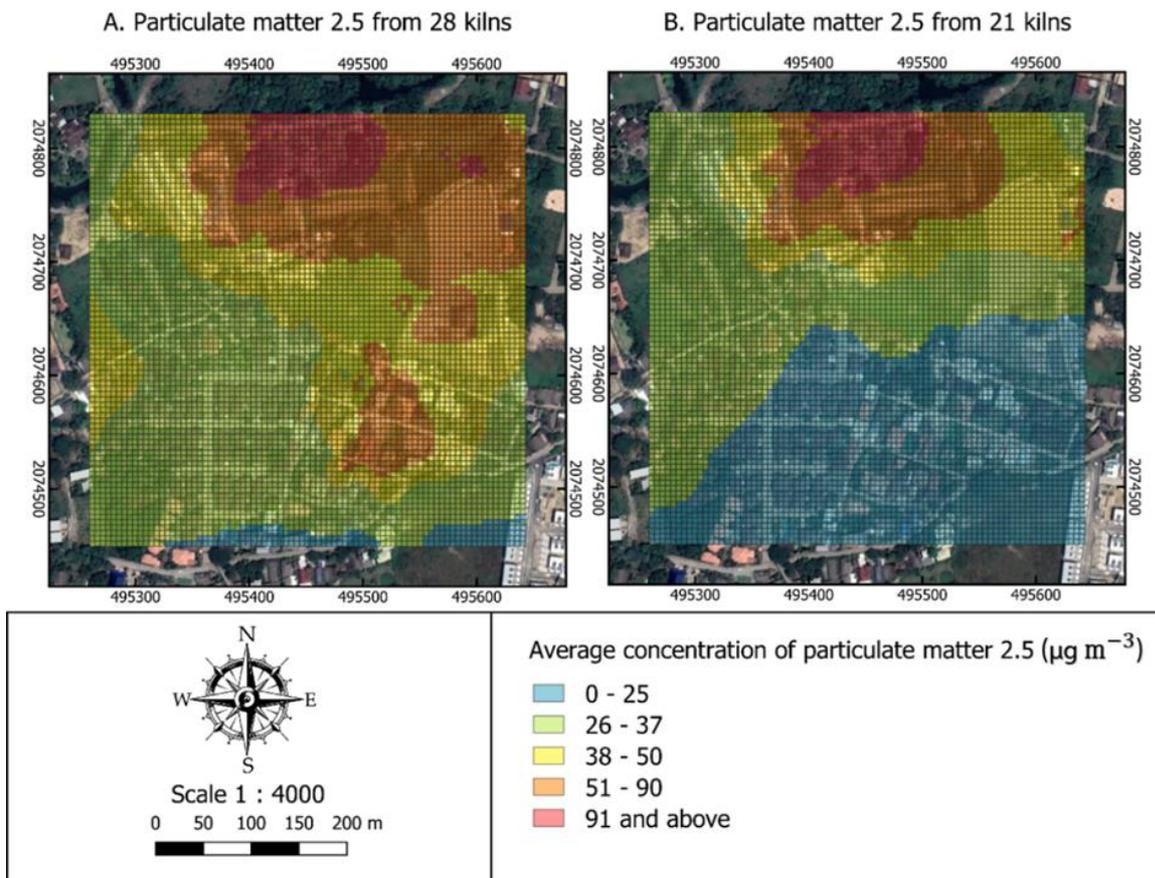
Note. A) Particulate matter 2.5 from 28 kilns, and B) Particulate matter 2.5 from 21 kilns. Adapted from *Average concentration of PM$_{2.5}$*, by Google Map, 2025 (https://www.google.co.th/maps/@18.7603388,98.9547671,16z?entry=ttu&g_ep=EgoyMDI1MDQyMy4wIKXMDSoASAFQAw%3D%3D). Copyright 2025 by Google LLC.

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Table 4

The Comparison of 24-Hour Average PM$_{2.5}$ Concentration During the Dry Summer Between the Maximum Use of 28 Brick Kilns and the Use of Only 21 Brick Kilns

Average PM$_{2.5}$ value for 24 hours during the dry summer	Study area: 200 x 200 meters Calculated distance: 5 x 5 meters					
	Using 28 stove-houses			Using 21 stove-houses		
Unit: Microgram per Cubic Meter	Average	Highest	Lowest	Average	Highest	Lowest
Kiln Capacity using (pcs. / time)	3,643	8,000	2,000	3,548	8,000	2,000
Max Using Fuel ß (kg/h)	188	350	117	178	350	117
PM$_{2.5}$ emission (g/s)	0.659	0.875	0.500	0.670	0.875	0.500
PM$_{2.5}$ (µg/m³)	48.21	209.19	21.36	34.67	203.49	13.62

Table 4 shows two cases of results which are (1) The model of the area brick kilns usage by 28 stove houses and (2) The model of 21 current brick kilns usage. The results show that the highest values of PM$_{2.5}$ concentration at the smoke point are 209.19 and 203.49 µg/m³, respectively, the average concentrations from both scenarios (48.21 and 34.67 µg/m³) exceeded WHO standards (25.00 µg/m³) and, in one case, exceeded Thailand's standard (37.50 µg/m³). Furthermore, the results present that the PM$_{2.5}$ concentration at the stack point is higher than the standard scores of both Thai (Amnuaylojaroen et al., 2022) and WHO general atmospheric air quality standards (Chankaew et al., 2022). The PM$_{2.5}$ concentrations support the need for zoning restrictions or filter retrofits in traditional kiln zones. One limitation is the reliance on modeled rather than real-time monitoring data, which may not account for dynamic microclimatic variations. This study highlights the environmental trade-offs inherent in preserving traditional practices, suggesting that sustainability measures must accompany cultural conservation efforts.

CONCLUSION

The average value of particle matter for 24 hours during the dry summer that was produced by 28 antique Mon-Lanna brickkilns in village No. 7 community, Suthep Subdistrict, Muang District, Chiang Mai Province when all of them were being worked at the same time, did affect the health of respiratory patients. Therefore, they should avoid any outdoor activities. Besides, general people, especially children and the elderly should stay indoors since the value of TSP has been at a harmful level. Moreover, due to the amount of PM$_{2.5}$ being in the yellow range, which could affect the health of respiratory patients, people are advised to avoid any outdoor exercising as well, as children and the elderly should not spend long periods doing outdoor activities. However, when seven antique "Mon" handmade brick kilns in the community were not in use on January 30, 2020 (the business had been closed down due to the economic conditions), the number of the most harmful airborne particles for health decreased to a level where it did not affect the health of people. Significantly, PM2.5 levels were reduced under the 21-kiln scenario. The average concentration (34.67 µg/m³) remained above WHO standards and approached the Thai limit (37.5 µg/m³), indicating continued health risks for sensitive populations. In summary, the calculation of the PM$_{2.5}$ concentration spreading from classical Mon-Lanna handmade brick kilns was done using the AERMOD modeling, the international standard for calculating the value of air pollution at the producing point. For more insight, the calculation used the numbers of types, fuel usage, and the emission factor value, which was

the same method that had been used in similar research and has been internationally accepted for open-air quality evaluation modeling in the community (Simões Amaral et al., 2016). Moreover, not only did this study prove the result of situation modeling, but it can also present the outcome in the map of PM$_{2.5}$ concentration spreading by using geographical information technology, which can be beneficial for urban physical resources management and further research on a higher level effectively (Manokeaw et al., 2021; Prasetia et al., 2021; Rzeszutek & Szulecka, 2021).

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