



Dust Alert Device: An Alternative for Real-time PM_{2.5} Monitoring to Support Disease Surveillance in Thailand with Performance Consistent Relative to Reference Measurements

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Abstract

Objectives: To assess the performance of the solar-powered, low-cost Dust Alert Device (DAD) for passive PM_{2.5} exposure screening and to evaluate its potential to strengthen air-quality surveillance in Thailand, where the limited spatial coverage of reference monitoring stations limits public health monitoring and risk communication.

Methods: A cross-sectional study was conducted using six DAD units installed between January and December 2024 at the Department of Disease Control and five international checkpoints. Real-time DAD measurements were compared with data from the nearest Air4Thai reference stations. Linear regression analysis was used to examine the relationship between DAD and reference measurements. Mean absolute error (MAE) and mean absolute percentage error (MAPE) were calculated by comparing observed Air4Thai reference with predicted air quality values based on DAD measurements. Sensitivity, and specificity at multiple thresholds (25, 37.5, and 75 µg/m³ for PM_{2.5}; 45 and 120 µg/m³ for PM₁₀) were also performed.

Results: Hourly PM_{2.5} concentrations measured by DAD showed an MAE of 8.6 µg/m³ and an MAPE of 53.6%, and this reduced to 24.2% when PM_{2.5} exceeded 37.5 µg/m³ with a sensitivity of 79.6%. The performance of DAD was most consistent with Air4Thai under cool and dry environmental conditions. These findings suggest that DAD is a consistent surveillance-oriented tool that can practically strengthen PM_{2.5} monitoring and risk communication.

Public Health Recommendations: Low-cost solar-powered sensors such as DAD can complement national monitoring networks by expanding spatial coverage, particularly in underserved or high-mobility locations such as border checkpoints. Integrating DAD data into routine surveillance and public communication platforms could improve early warning systems, support targeted health advisories, and enhance risk awareness among vulnerable populations. Further calibration methods and environmental adjustment models are recommended to improve accuracy across seasonal and climatic conditions.

Keywords: PM_{2.5}, low-cost air-quality sensors, air pollution, public health surveillance, passive screening



Introduction

Fine particulate matter with an aerodynamic diameter of ≤ 2.5 micrometers ($PM_{2.5}$) is widely recognized as a major environmental health concern. The World Health Organization has suggested that exposure to elevated $PM_{2.5}$ has been associated with adverse respiratory and cardiovascular health outcomes.¹ In Thailand, respiratory diseases account for a substantial proportion of illnesses attributable to environmental factors, underscoring the ongoing need for an effective $PM_{2.5}$ surveillance system.^{2,3}

To mitigate health impacts from air pollution, the Ministry of Public Health (MOPH) has implemented a passive health screening approach for $PM_{2.5}$, particularly focusing on high-risk populations such as children, older adults, and individuals with chronic conditions. This approach relies on confirmation that the daily average $PM_{2.5}$ concentration exceeds national standards, together with documentation of environmental exposure using the International Classification of Diseases, Tenth Revision (ICD-10). The ICD-10 codes referring to $PM_{2.5}$ exposure include Z58.1 (exposure to air pollution) and Y97 (environmental factors related to pollution). These codes are recorded as supplementary codes alongside primary diagnostic codes for four target disease groups: respiratory diseases, dermatological diseases, eye diseases, and cardiovascular diseases, to support surveillance of $PM_{2.5}$ -related health impacts.^{4,5}

At present, $PM_{2.5}$ monitoring in Thailand is primarily conducted through the Air4Thai system, a national reference air quality monitoring network operated by the Pollution Control Department. However, in some rural and border areas, the spatial distribution of monitoring stations, as well as limitations related to distance and connectivity, may restrict timely access to location-specific $PM_{2.5}$ data.

In Health Region 8, $PM_{2.5}$ concentrations have been consistently elevated, with an annual average in 2024 of $27.0 \mu\text{g}/\text{m}^3$, exceeding the national standard of $15 \mu\text{g}/\text{m}^3$, and frequent exceedances of the 24-hour standard of $37.5 \mu\text{g}/\text{m}^3$. Under this context, the recording of $PM_{2.5}$ -related ICD-10 codes remains relatively low, with Z58.1 and Y97 documented in only 0.21% and 2.30% of total cases, respectively (both below 5%).⁶ This discrepancy highlights an opportunity to strengthen the linkage between air quality data and health surveillance systems.

To address this gap, the Office of Disease Prevention and Control Region 8 Udon Thani and the Division of Digital Disease Control, Department of Disease

Control (DDC), developed a Dust Alert Device (DAD). The DAD is a low-cost $PM_{2.5}$ monitoring device powered by solar energy and based on the light-scattering measurement technique. It employs the Plantower PMS5003 sensor, like the DustBoy device developed by Chiang Mai University, which has demonstrated high accuracy when compared with the United States Environmental Protection Agency (US-EPA)-approved Teledyne Model 640.⁷ Both instruments utilize the light-scattering technique, which is an internationally accepted method and is recognized by the National Environmental Board of Thailand.^{7,8} In addition, DAD is equipped with a built-in red visual alert light that provides an immediate, high-visibility risk signal when $PM_{2.5}$ concentrations exceed predefined thresholds, thereby increasing awareness among both service users and health personnel. The DAD was designed to complement existing monitoring systems by providing real-time and area-specific $PM_{2.5}$ data, particularly in locations where reference monitoring stations are remote or have limited accessibility.

The objective of this study is to assess the performance of the DAD by examining the consistency of $PM_{2.5}$ estimates obtained from the DAD in comparison with the Air4Thai reference system. The findings of this study are expected to inform further exploration of the potential role of the DAD in supporting passive health screening and $PM_{2.5}$ -related public health surveillance in Thailand.

Methods

Study Design

We employed a cross-sectional comparative design to evaluate the performance of the DAD against reference-grade Air4Thai monitoring stations, covering the period from January to December 2024.

Study Setting and Monitoring Sites

In 2024, six DAD units were installed, one at the DDC headquarters and five at international checkpoints under the Office of Disease Prevention and Control Region 8 Udon Thani. Devices were installed 1.8 meters above ground in open, sun-exposed areas near passenger arrival gates, with data transmitted in real time to health officers for border risk communication.

At the DDC, the DAD and Air4Thai monitors were located approximately 50 meters apart, providing a near co-located comparison. Apart from the DDC headquarters station, the distances between each DAD's station and its nearest Air4Thai station were as follows:

(1) Ban Phan Lam Pier Station—6.2 km from Bueng Kan Public Park, (2) Third Thai-Lao Friendship Bridge Station—10 km from Nakhon Phanom Meteorological Department, (3.1) First Thai-Lao Friendship Bridge Station—1.1 km from Nong Thin Public Park, (3.2) Nong Khai Railway Station—1.4 km from Nong Thin Public Park, and (4) Udon Thani Airport Station—3.5 km from Nong Prajak Public Park. One of the key reasons for situating DAD and Air4Thai at different locations within each pair is that the DAD units were intentionally installed at border checkpoints to reflect real-world operational surveillance conditions, where air quality may be partially influenced by dust or smoke from agricultural burning in neighboring countries. Despite the spatial separation (1–10 km), each DAD–Air4Thai pair was located within the comparable similar geographic and meteorological context (airshed) and was primarily influenced by similar regional PM_{2.5} source patterns.⁹

Statistical Analysis

Descriptive analysis

Hourly DAD and Air4Thai data were summarized by sites and months. For each day, the number of valid hourly readings contributing to the 24-hour mean was recorded. The number of days in which PM_{2.5} levels exceeded 37.5 µg/m³ (passive screening threshold) and the number of EOC activation events (PM_{2.5} > 75 µg/m³ for ≥3 consecutive days) were computed by site and month.

Regression modeling

To evaluate DAD performance, Air4Thai data was used as the reference standard. Both DAD and Air4Thai provided hourly PM_{2.5} data, which were paired by timestamp. The Wilcoxon signed-rank test was used to assess differences between DAD and Air4Thai measurements. A linear regression model was fit to estimate PM_{2.5} values from DAD measurements, as shown in equation (1).

$$\hat{y}_i = \beta_0 + \beta_1(DAD_PM_i) \text{ ---- (1)}$$

where $\hat{y}_i$ is the predicted Air4Thai PM_{2.5} for hour i , DAD_PM_i is the PM_{2.5} value measured by DAD for hour i , β_0 is the intercept, and β_1 represents the change per 1 µg/m³ increase in PM_{2.5}.

Observed DAD measurements were used to evaluate sensitivity and specificity, whereas regression-predicted values were generated for bias characterization.

Error metrics

We calculated mean absolute error (MAE) and mean absolute percentage error (MAPE) as defined in equations (2) and (3), respectively:

$$MAE = \frac{1}{n} \sum_{i=1}^n |y_i - \hat{y}_i| \text{ ---- (2)}$$

$$MAPE = \frac{100}{n} \sum_{i=1}^n \left| \frac{y_i - \hat{y}_i}{y_i} \right| \text{ ---- (3)}$$

where y_i is the observed Air4Thai PM_{2.5} for hour i and $\hat{y}_i$ refers to the predicted dust particulate values from the model based on DAD readings. Lower MAE and MAPE values indicate lower measurement discrepancy.^{10,11} R² was also calculated to measure the agreement between DAD-predicted and Air4Thai PM concentrations.

Model performance was analyzed under four exposure scenarios. The first scenario, overall data, represented general accuracy of the model across all measured PM_{2.5} levels. The second scenario corresponded to the public health precaution level, defined as instances when hourly PM_{2.5} concentrations exceeded 37.5 µg/m³, indicating conditions that may pose health risks. The third scenario assessed the passive screening threshold, applied when the 24-hour average PM_{2.5} concentration surpassed 37.5 µg/m³, which is the national standard for initiating health screening activities in public health facilities. Finally, the EOC activation threshold scenario examined periods when PM_{2.5} levels exceeded 75 µg/m³ for more than three consecutive days, a condition that triggers the activation of the EOC for PM_{2.5} events. All cut-off levels were determined using Air4Thai measurements as the reference.

Environmental Stratification (Temperature and Relative Humidity)

Environmental influences on sensor performance were explored by stratifying data according to temperature and relative humidity. Environmental stratification by temperature and relative humidity was performed using measurements from the Air4Thai reference stations to maintain consistency with the reference standard. Each variable was dichotomized into “high” or “low” based on median values recorded at each station. Comparison between DAD and Air4Thai readings under these environmental conditions was conducted using linear regression and performance metrics.

Sensitivity and Specificity

The public health applicability of the DAD was assessed by calculating its sensitivity and specificity for detecting elevated PM_{2.5} concentrations to support haze-related surveillance and response systems.

Three PM_{2.5} concentration threshold levels were used for analysis: 1) 25 µg/m³ (stringent threshold), 2) 37.5 µg/m³ (health effects among vulnerable populations—practical thresholds applied in many nations), and 3) 75 µg/m³ (health effects on the general population). For PM₁₀, the cut-off points were 45 µg/m³ and 120 µg/m³, representing risk levels for vulnerable and general populations, respectively.^{8,12}

Hourly PM_{2.5} measurements from both observed DAD and Air4Thai were converted into binary variables based on the abovementioned thresholds. Sensitivity and specificity were calculated using two-by-two

contingency tables, and 95% confidence intervals (CIs) were estimated using the exact binomial (Clopper–Pearson) method. Observations with missing values in any required variables were excluded from the analysis.

Statistical Software

All statistical analyses and data visualizations were conducted using R version 4.4.1; R Core Team (2024).

Results

Description of Observations

Each DAD station recorded between 2,280 and 7,012 valid hourly measurements from January to December 2024. The highest data volume was found at Nong Khai Bridge (7,012 hours), followed by Bueng Kan (6,725) and Udon Thani (6,537), while Nakhon Phanom (2,280) recorded the fewest due to mid-year data interruptions (Table 1).

Table 1. Total hours of Dust Alert Device (DAD) PM_{2.5} data included in the analysis at each site, 1 Jan–31 Dec 2024.

Month	DAD location					
	Bueng Kan	DDC headquarters	Nakhon Phanom	Nong Khai Bridge	Nong Khai Railway Station	Udon Thani
January	299	630	23	348	677	262
February	631	648	598	569	589	635
March	686	603	694	679	682	658
April	515	479	518	516	518	444
May	531	521	109	531	532	520
June	686	625	203	681	681	655
July	419	453	40	415	405	423
August	528	456	12	539	536	483
September	655	551	24	671	671	437
October	708	567	41	711	100	711
November	596	394	18	685	0	682
December	471	221	0	663	0	663
Total	6,725	6,331	2,280	7,012	5,394	6,537

DAD: Dust Alert Device. DDC: Department of Disease Control.

Across all sites, the median PM_{2.5} concentrations were 18.6 µg/m³ (DAD) and 18.4 µg/m³ (Air4Thai) (*p*-value <0.001), and PM₁₀ concentrations were 25.4 µg/m³ (DAD) and 44.0 µg/m³ (Air4Thai) (*p*-value <0.001).

Differences between instruments were statistically significant at all sites (*p*-value <0.05), except for PM₁₀ in Bueng Kan, where Air4Thai data was unavailable (Table 2).

Table 2. Number of days in a month when the Dust Alert Device (DAD)'s daily average PM_{2.5} exceeded 37.5 µg/m³, 1 Jan–31 Dec 2024.

Month	Bueng Kan			DDC headquarters			Nakhon Phanom			Nong Khai Bridge			Nong Khai Railway Station			Udon Thani		
	A4T	DAD	Valid days*	A4T	DAD	Valid days*	A4T	DAD	Valid days*	A4T	DAD	Valid days*	A4T	DAD	Valid days*	A4T	DAD	Valid days*
January	0	1	12	12	16	27	NA	NA	0	2	1	8	9	8	30	0	5	10
February	3	19	27	4	10	29	12	11	25	17	16	24	18	17	25	15	23	29
March	12	23	30	2	4	29	23	12	30	12	23	29	13	19	29	18	21	29
April	22	22	22	1	2	22	21	7	21	11	21	22	11	17	22	15	17	18
May	0	0	23	0	1	23	NA	NA	0	0	0	23	0	0	23	0	0	22
June	0	0	30	0	0	30	0	0	2	0	0	30	0	0	30	0	0	30
July	0	0	13	0	0	15	NA	NA	0	0	0	11	0	0	11	0	0	14
August	0	0	23	0	0	21	NA	NA	0	0	0	23	0	0	23	0	0	18
September	0	0	30	0	0	22	NA	NA	0	0	0	29	0	0	29	0	0	19
October	0	5	31	0	0	22	NA	NA	0	2	0	31	0	0	3	1	5	31
November	0	0	26	0	1	7	NA	NA	0	5	0	30	NA	NA	0	0	3	30
December	0	1	20	NA	NA	0	NA	NA	0	9	0	28	NA	NA	0	1	5	28
Total	37	71	287	19	34	247	56	30	78	58	61	288	51	61	225	50	79	278

*Valid days were defined as days with ≥ 18 hourly PM_{2.5} measurements (00:00–24:00; $\geq 75\%$ daily completeness); A4T and DAD columns indicate the number of valid days in which daily average PM_{2.5} exceeded 37.5 µg/m³; Zero indicates that the daily average PM_{2.5} did not exceed 37.5 µg/m³ on any day in the month. NA indicates that daily data were not available. DDC: Department of Disease Control. A4T: Air4Thai. DAD: Dust Alert Device.

Daily average PM_{2.5} levels exceeded 37.5 µg/m³ mainly between January and April, with no exceedances from May to September (Table 3). The highest exceedance frequencies were observed in Udon Thani (79 days) and

Bueng Kan (71 days), while Nakhon Phanom (30 days) and DDC Nonthaburi (34 days) reported the fewest. Overall, DAD recorded more daily exceedances than Air4Thai, particularly during peak haze months.

Table 3. Comparison of PM_{2.5} and PM₁₀ concentration values measured by Air4Thai and Dust Alert Device (DAD) at various monitoring sites.

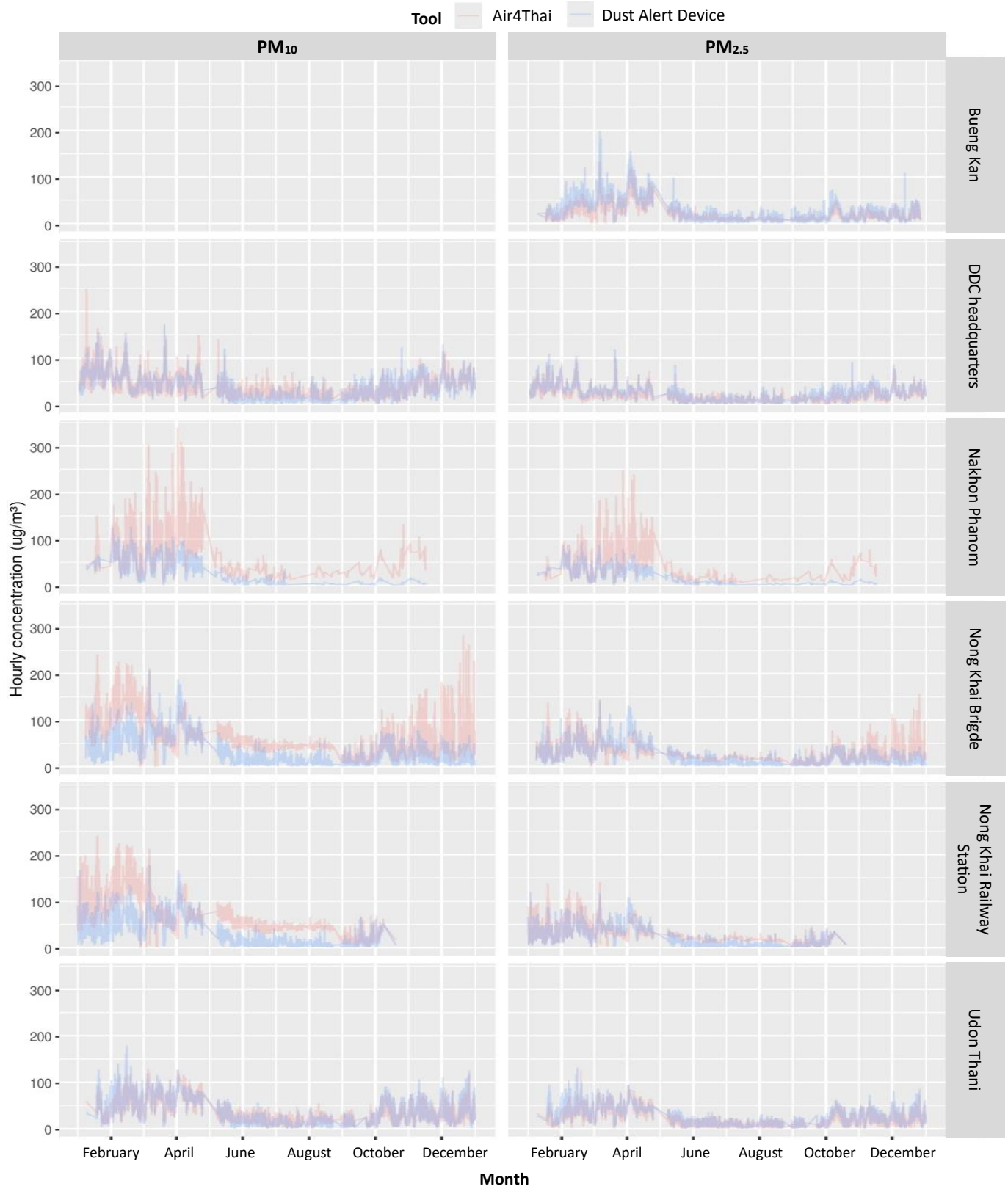
Monitoring site (location)	Particulate matter concentration (µg/m³)					
	PM _{2.5}		P-value*	PM ₁₀		P-value*
	Air4Thai	DAD		Air4Thai	DAD	
Station 1 (Bueng Kan)			<0.001			-
Arithmetic means	20.54	26.13		-	35.36	
Median	13.80	17.90		-	22.60	
Station 2 (DDC headquarters)			<0.001			<0.001
Arithmetic means	18.85	22.88		37.04	36.18	
Median	15.40	21.20		31.00	32.80	
Station 3 (Nakhon Phanom)			<0.001			<0.001
Arithmetic means	51.36	28.67		76.41	42.27	
Median	47.20	29.80		70.00	41.85	
Station 4 (Nong Khai Bridge)			<0.001			<0.001
Arithmetic means	26.60	21.37		61.39	31.13	
Median	20.90	13.20		49.00	18.60	
Station 5 (Nong Khai Railway Station)			<0.001			<0.001
Arithmetic means	27.23	21.70		67.83	32.23	
Median	20.80	13.60		57.00	19.00	
Station 6 (Udon Thani)			<0.001			<0.001
Arithmetic means	22.19	25.86		36.21	37.27	
Median	17.40	21.00		29.00	28.20	
All sites			<0.001			<0.001
Arithmetic means	24.89	23.98		52.46	35.00	
Median	18.60	18.40		44.00	25.40	

*Wilcoxon signed-rank test. DAD: Dust Alert Device. DDC: Department of Disease Control.

Comparison of Hourly $PM_{2.5}$ and PM_{10} Concentrations at Each Station

At Station 3 (Nakhon Phanom Province), $PM_{2.5}$ values measured by Air4Thai were higher during the early months of the year. Most monitoring sites recorded

relatively high $PM_{2.5}$ levels in the first quarter (January–March), which then decreased during the rainy and winter seasons. The PM_{10} concentration trends from both devices were also similar, with elevated levels observed at the beginning of the year, corresponding to those of $PM_{2.5}$ (Figure 1).



DDC: Department of Disease Control

Figure 1. Hourly concentrations of $PM_{2.5}$ and PM_{10} , separated by monitoring sites, January to December 2024

Comparison of Error Metrics between Predicted PM_{2.5} and PM₁₀ Concentrations

For MAE, the measurement error of predicted PM_{2.5} based on DAD, compared with Air4Thai, ranged from 4.5 to 16.3 µg/m³. R² values ranged from 60.8% to 82.4% across stations. At DDC, the MAE was 4.5 µg/m³. In Udon Thani (6.6 µg/m³), the error was lower

than those observed in Nakhon Phanom (16.3 µg/m³) and Nong Khai (7.5 µg/m³). The average MAE across all sites was 8.6 µg/m³ for PM_{2.5} and 21.9 µg/m³ for PM₁₀. The MAE of PM₁₀ was significantly higher than that of PM_{2.5} at all sites. Further analysis by relative humidity and temperature revealed that, in many stations, the MAE tended to decrease under dry or low-temperature conditions (Table 4).

Table 4. Comparison of mean absolute error (MAE) between predicted hourly PM_{2.5} and PM₁₀ concentrations based on Dust Alert Device (DAD) measures and Air4Thai reference at each monitoring site.

Monitoring site (location)	PM _{2.5}					PM ₁₀				
	All data	Classified by RH level*		Classified by T level†		All data	Classified by RH level*		Classified by T level†	
		Low	High	Low	High		Low	High	Low	High
Station 1 (Bueng Kan)										
All data	4.86	5.74	3.93	4.53	5.22	-	-	-	-	-
PM _{2.5} >37.5µg/m³	6.85	6.14	7.63	7.81	5.59	-	-	-	-	-
Station 2 (DDC headquarters)										
All data	4.52	4.45	4.60	4.66	4.34	9.78	8.19	11.40	9.81	9.73
PM _{2.5} >37.5µg/m³	5.22	5.12	5.33	5.42	5.01	-	-	-	-	-
Station 3 (Nakhon Phanom)										
All data	16.27	17.70	14.70	15.20	17.40	22.16	23.80	20.40	20.70	23.80
PM _{2.5} >37.5µg/m³	24.14	26.60	21.40	23.50	25.00	-	-	-	-	-
Station 4 (Nong Khai Bridge)										
All data	7.47	8.20	6.73	8.35	6.53	21.15	22.50	19.70	22.40	19.80
PM _{2.5} >37.5µg/m³	12.89	11.20	14.70	13.90	11.90	-	-	-	-	-
Station 5 (Nong Khai Railway Station)										
All data	7.43	7.57	7.29	7.96	6.75	21.43	26.20	16.70	23.70	18.60
PM _{2.5} >37.5µg/m³	12.56	11.10	14.10	12.70	12.40	-	-	-	-	-
Station 6 (Udon Thani)										
All data	6.61	7.30	5.87	6.26	7.00	8.78	9.19	8.37	8.80	8.75
PM _{2.5} >37.5µg/m³	7.73	8.73	6.73	6.96	8.63	-	-	-	-	-
All sites										
All data	8.60	8.55	8.65	8.69	8.50	21.86	19.80	23.90	23.10	20.30
PM _{2.5} >37.5µg/m³	14.69	13.70	15.70	15.50	13.80	-	-	-	-	-

*Relative humidity (RH) measured by Air4Thai, using the median value as the cut-off point for high and low levels. †Temperature (T) measured by Air4Thai, using the median value as the cut-off point for high and low levels. DAD: Dust Alert Devices. DDC: Department of Disease Control.

The corresponding MAPE across all monitoring stations averaged 53.6%, with the lowest value at DDC (33.5%). When PM_{2.5} concentrations exceeded 37.5 µg/m³, the average MAPE decreased markedly to 24.2%, reaching

10.1% at DDC. The errors were lessened under dry conditions, while temperature effects varied among stations. For PM₁₀, errors were consistently higher, with an average MAPE of 61.4% across all sites (Table 5).

Table 5. Comparison of mean absolute percentage error (MAPE) between predicted hourly PM_{2.5} and PM₁₀ concentrations based on Dust Alert Device (DAD) measures and Air4Thai reference at each monitoring site.

Monitoring site (location)	Air4Thai versus DAD For PM _{2.5}					Air4Thai versus DAD For PM ₁₀				
	All data	Classified by RH level*		Classified by T. level†		All data	Classified by RH level*		Classified by T. level†	
		Low	High	Low	High		Low	High	Low	High
Station 1 (Bueng Kan)										
All data points	35.17	40.50	29.60	32.70	38.00	-	-	-	-	-
PM _{2.5} >37.5µg/m³	12.49	11.60	13.50	13.90	10.60	-	-	-	-	-
Station 2 (DDC headquarters)										
All data	4.52	4.45	4.60	4.66	4.34	9.78	8.19	11.40	9.81	9.73
PM _{2.5} >37.5µg/m³	5.22	5.12	5.33	5.42	5.01	-	-	-	-	-
Station 3 (Nakhon Phanom)										
All data points	40.40	41.11	39.60	50.30	29.60	34.90	32.30	36.00	33.20	35.10
PM _{2.5} >37.5µg/m³	30.81	31.30	30.20	31.80	29.50	-	-	-	-	-
Station 4 (Nong Khai Bridge)										
All data points	39.71	53.90	25.30	53.90	24.40	54.10	48.20	58.70	50.10	56.90
PM _{2.5} >37.5µg/m³	22.06	20.10	24.20	20.50	23.70	-	-	-	-	-
Station 5 (Nong Khai Railway Station)										
All data points	45.25	63.70	26.70	60.90	25.40	58.40	55.10	62.30	58.00	59.60
PM _{2.5} >37.5µg/m³	21.37	20.20	22.60	18.90	24.30	-	-	-	-	-
Station 6 (Udon Thani)										
All data	6.61	7.30	5.87	6.26	7.00	8.78	9.19	8.37	8.80	8.75
PM _{2.5} >37.5µg/m³	7.73	8.73	6.73	6.96	8.63	-	-	-	-	-
All sites										
All data points	53.59	51.90	55.40	59.50	47.10	61.40	46.80	50.40	47.10	50.40
PM _{2.5} >37.5µg/m³	24.17	23.00	25.40	24.60	23.70	-	-	-	-	-

*Relative humidity (RH) measured by Air4Thai, using the median value as the cut-off point for high and low levels. [†]Temperature (T) measured by Air4Thai, using the median value as the cut-off point for high and low levels. DAD: Dust Alert Devices. DDC: Department of Disease Control.

Sensitivity and Specificity of DAD in Classifying PM_{2.5} and PM₁₀ Concentrations

At a PM_{2.5} threshold of 25 µg/m³, the DAD achieved a sensitivity of 87.5% (95% CI 86.9–88.1) and a specificity of 85.2% (95% CI 84.7–85.7%), indicating few false alarms in detecting exceedances. Increasing the threshold to 37.5 µg/m³ reduced the sensitivity to 79.6% (95% CI 78.6–80.5%), while the specificity

increased to 89.2% (95% CI 88.9–89.6%), suggesting improved ability to correctly identify non-exceedance (safe) concentrations. At the 75 µg/m³ threshold, the sensitivity decreased to 20.3% (95% CI 17.9–22.8), whereas the specificity increased to 98.6% (95% CI 98.4–98.7%), indicating that DAD could almost perfectly identify safe concentrations with a tradeoff with compromised ability to detect most extreme polluted events (Table 6).

Table 6. Sensitivity and specificity of Dust Alert Device (DAD) compared with Air4Thai in measuring PM_{2.5} and PM₁₀ concentrations.

Cut-off level	True positive	True negative	False positive	False negative	Sensitivity (%) [95% CI]	Specificity (%) [95% CI]
PM_{2.5} concentration (µg/m³)						
25	10,770	18,753	3,259	1,533	87.50 [86.90–88.10]	85.20 [84.70–85.70]
37.5	5,240	24,742	2,988	1,345	79.60 [78.60–80.50]	89.20 [88.90–89.60]
75	213	32,792	473	837	20.30 [17.90–22.80]	98.60 [98.40–98.70]
PM₁₀ concentration (µg/m³)						
45	7,743	12,860	1,663	5,267	59.50 [58.70–60.40]	88.50 [88.00–89.10]
120	53	25,614	130	1,736	3.00 [2.20–3.90]	99.50 [99.40–99.60]

CI: confidence interval.

In comparing PM₁₀ measurements between DAD and Air4Thai using cut-off points of 45 and 120 µg/m³ (Table 6), DAD had a sensitivity of 59.5% (95% CI 58.7–60.4%) and specificity of 88.5% (95% CI

88.0–89.1%) at the 45 µg/m³ threshold. When the threshold increased to 120 µg/m³, the sensitivity decreased to 3.0% (95% CI 2.2–3.9%), whereas the specificity increased to 99.5% (95% CI 99.4–99.6%).

Discussion

This study demonstrates that the Dust Alert Device (DAD) captures temporal patterns of PM_{2.5} and PM₁₀ concentrations comparable to those observed by the Air4Thai. Although absolute differences were observed, these varied systematically with pollution intensity and environmental conditions, supporting the interpretability of DAD data for surveillance purposes.

Daily average PM_{2.5} concentrations exceeded the national standard (37.5 µg/m³) mainly between January and April, corresponding to the dry season and recurrent regional haze episodes. The highest numbers of exceedance days were observed in Udon Thani and Bueng Kan, areas strongly influenced by transboundary pollution and agricultural burning. No exceedances were observed from May to September, highlighting the mitigating effect of monsoonal rainfall. DAD tended to record more exceedance days than Air4Thai during peak haze months.

Hourly PM_{2.5} and PM₁₀ comparisons showed similar seasonal variation patterns between DAD and Air4Thai, with elevated concentrations in the first quarter followed by declines during the rainy season. This concordance indicates that DAD reliably captures relative temporal changes in air quality, a key requirement for surveillance and early warning applications.

Error metrics showed acceptable agreement between the two systems, with MAE values averaging 8.6 µg/m³ for PM_{2.5} and 21.9 µg/m³ for PM₁₀. Lower errors were observed at stations with more stable environmental conditions. Measurement performance improved under dry or low-temperature conditions, consistent with known limitations of optical light-scattering sensors at high relative humidity.¹³ In addition, MAPE provided complementary insight into DAD performance. Overall, the predicted measures based on DAD values achieved a mean MAPE of 53.6% for PM_{2.5}. During periods of high pollution (>37.5 µg/m³), MAPE decreased to 24.2% across sites and 10.1% at the DDC station. This pattern indicates better DAD performance when particulate concentrations were elevated, likely due to an improved signal-to-noise ratio of the optical sensor. In contrast, PM₁₀ measurements exhibited consistently higher errors, with an average MAPE of 61.4%, reflecting greater variability associated with broader coarse particle size distributions and increased scattering uncertainty.¹⁴ Relatively R² values were observed across stations, with moderate to strong agreement between DAD and Air4Thai, particularly during high-pollution periods and at stations with

lower MAE and. This pattern is consistent with previous low-cost sensor validation studies. Comparable optical systems, such as DustBoy, have reported high R² values when benchmarked against United States Environmental Protection Agency reference monitors.⁷

Sensitivity and specificity values further support the public health relevance of DAD. At moderate PM_{2.5} thresholds (25 µg/m³), DAD achieved high sensitivity (87.5%) and specificity (85.2%), enabling effective identification of exceedance events with few false alarms. As thresholds increased, sensitivity decreased while specificity increased, reflecting a trade-off inherent to screening-oriented monitoring systems. This trade-off resulted in under-detection of extreme pollution events but reliable identification of safe conditions, a pattern that was more pronounced for PM₁₀, where sensitivity decreased to 3% at the 120 µg/m³ threshold despite near-perfect specificity (99.5%). From a surveillance and response perspective, this sensitivity–specificity trade-off is acceptable in public health screening, as DAD is intended to support early warning and risk communication under real-world deployment constraints rather than precise detection of rare extreme pollution events. These findings also highlight the potential value of periodic calibration or algorithmic correction during severe pollution episodes to enhance DAD responsiveness.

Limitations

Some limitations of this study should be acknowledged. First, the DAD units were not exactly co-located with the Air4Thai reference stations. Each DAD was paired with the nearest Air4Thai station within the same geographic area and a comparable airshed⁹; however, the spatial separation may have introduced variability attributable to local microenvironmental differences. Nevertheless, this spatial separation was intentionally retained, as it more accurately reflects real-world public health surveillance conditions under which the DAD would be deployed. To address this limitation, future studies with co-located or rotating deployments could further reduce this uncertainty. Second, this study did not comprehensively examine all operational feasibility aspects of DAD. To introduce DAD into real-world settings, additional operational factors such as maintenance requirements and comprehensive feasibility analysis should also be considered.

Public Health Recommendations

DAD should be installed in dry, shaded, and low-humid outdoor areas as its performance was optimal

under these conditions. The device is most reliable for detecting PM_{2.5} levels above 37.5 µg/m³ and can be used as an early warning tool to support passive health screening and risk communication in public-health facilities. The built-in visual alert system provides a clear and immediate risk signal, strengthening evidence-based risk communication and improving passive screening by increasing awareness among both service users and health personnel. DAD data may also be integrated into routine public health surveillance systems to enhance situational awareness during haze episodes. For severe pollution events, DAD readings should be supplemented with reference-grade monitors or nearby Air4Thai data due to reduced sensitivity at very high PM_{2.5} concentrations.

Conclusion

Overall, DAD effectively provides early warning when PM_{2.5} concentrations exceed 37.5 µg/m³, achieving a sensitivity of 79.6%, and a specificity of 89.2% compared with reference Air4Thai monitors. These results indicate that DAD detects elevated PM_{2.5} events in approximately 80% of cases while accurately identifying non-high-exposure conditions in nearly 90% of cases, thereby minimizing false alarms. Performance was enhanced under dry and cool conditions. Taken together, these findings support the use of DAD as a supplemented early warning tool for PM_{2.5}-related health risks among at-risk populations in public-health facilities.

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Authors Contributions

Waraluk Tangkanakul: Conceptualization; data acquisition; writing—original draft, writing—review & editing. **Wilailak Saengsri:** Methodology, writing—original draft, writing—review & editing. **Voravit Payungkiatbawon:** Writing—review & editing. **Sutham Jirapanakorn:** Writing—original draft, writing—review & editing. **Rapeepong Suphanchaimat:** Conceptualization, methodology, writing—original draft, writing—review & editing.

Ethical Approval

This study was conducted as part of the disease surveillance activities carried out by the Office of Disease Prevention and Control Region 8 Udon Thani, and the Division of Occupational and Environmental Diseases. It relied on anonymized secondary air-quality monitoring data and did not involve human participants; therefore, ethical approval was not required.

Informed Consent

Not applicable.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

None.

Funding Support

None.

Declaration of Generative-AI and AI-assisted Technologies in the Writing Process

Artificial intelligence tools (ChatGPT, OpenAI) were used to support language editing and refinement of the manuscript. All analyses, interpretations, and final decisions were made solely by the authors, who take full responsibility for the content.

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