Atmospheric Drivers of $PM_{2.5}$ Variability: Relative Humidity and Rainfall Influence in Tha Sala, Nakhon Si Thammarat Province

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Abstract

This study compares the effects of relative humidity (RH%) and rainfall on ambient particulate matter ($PM_{2.5}$) concentrations. While rainfall cleanses the atmosphere via wet deposition, high RH% can increase $PM_{2.5}$ concentration through hygroscopic growth and secondary aerosol formation. Data were analyzed across three distinct Nakhon Si Thammarat sites: an educational zone, a high-density urban area, and a suburban/rural village. Results confirm that rainfall is the primary mechanism for $PM_{2.5}$ removal across all environments. Conversely, a significant positive correlation was observed between RH% and $PM_{2.5}$ (due to formation/growth), particularly in urban areas. The findings quantify the differential meteorological control over air quality and emphasize the necessity of site-specific data for accurate $PM_{2.5}$ forecasting and policy development.

Keywords: $PM_{2.5}$; Relative Humidity; Rainfall; Air Quality; Spatial Variation; Meteorological Factors.

1. Introduction

Air quality is a critical global concern, with particulate matter ($PM_{2.5}$)—airborne particles with an aerodynamic diameter of 2.5 µm or less—recognized as one of the most detrimental pollutants to human health and visibility. $PM_{2.5}$ concentration in the atmosphere is a complex function of both anthropogenic emissions (e.g., industrial activities, traffic, biomass burning) and natural processes, which are primarily governed by meteorological conditions. Understanding how weather variables influence the dispersion, formation, and removal of these fine particles is essential for developing accurate forecasting models and effective air quality management strategies. Among the various meteorological factors, atmospheric moisture—specifically relative humidity (RH%) and rainfall (precipitation)—plays a multifaceted and often contrasting role in modulating $PM_{2.5}$ levels. Relative Humidity (RH%): High relative humidity can significantly affect $PM_{2.5}$ concentrations. Via hygroscopic growth, in which particles absorb moisture and increase in size. This growth can enhance light scattering, thereby reducing visibility, and accelerate the formation of secondary aerosols (e.g., sulfates and nitrates) via aqueous-phase chemical reactions. Conversely, if particles become sufficiently heavy, high RH% may also facilitate their removal via increased gravitational settling (dry deposition). However, the correlation between RH% and $PM_{2.5}$ can be site-specific, sometimes showing a positive relationship (due to secondary formation and growth) or a negative one (due to deposition). Rainfall (Precipitation): Rainfall is widely regarded as one of the most effective natural cleansing mechanisms for the atmosphere. Its influence is primarily through wet deposition—specifically in-cloud scavenging (rainout) and below-cloud scavenging (washout)—which physically removes particulate matter from the air. Generally, precipitation events are associated with a notable decrease in $PM_{2.5}$ concentrations. However, the efficiency of this removal (scavenging efficiency) depends on factors such as rainfall intensity, duration, and initial pollution level. The combined yet distinct physical and chemical mechanisms by which RH% and rainfall affect delicate particulate matter make their comparative influence a compelling area of study. While rainfall offers a precise removal mechanism, RH% simultaneously facilitates both the formation/growth of $PM_{2.5}$ and, under certain conditions, its eventual deposition. This study aims to examine the complex interactions between atmospheric humidity variables (specifically, relative humidity and rainfall) and $PM_{2.5}$ concentrations across diverse geographic and environmental settings. To achieve this goal, the study will focus on three different locations: (1) Walailak University, Nakhon Si Thammarat Province (educational zone), (2) Houses near Walailak University (high-density urban environment), and (3) Villages in Tha Sala District (suburban/rural environment).

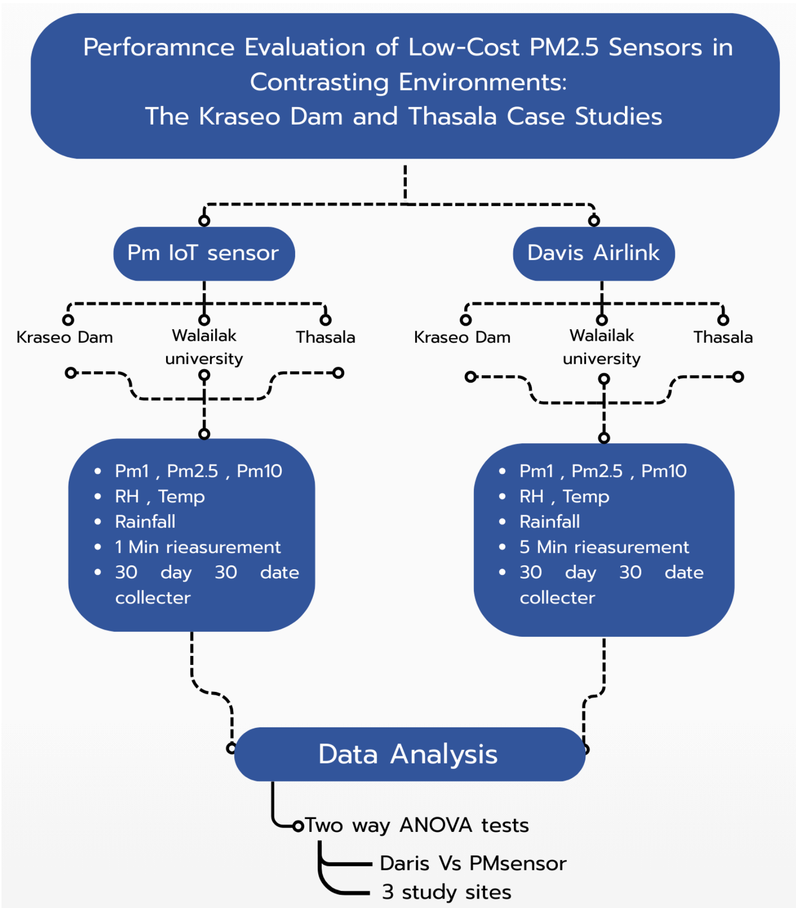


Figure 1: Experimental Design

2- Materials and Methods

2-1- Study Site

Field surveys were conducted at two locations in Thailand: (1) Walailak University, Nakhon Si Thammarat Province (8.642305°N, 99.89164°E), (2) Houses near Walailak University (8.651416°N, 99.915653°E), and (3) A village in Tha Sala District (8.671438°N, 99.921900°E). The Davis AirLink $PM_{2.5}$ sensor, the Plantower Laser $PM_{2.5}$ dust sensor, and the PMS 3003 low-cost sensor were installed at all three locations to measure $PM_{2.5}$ concentration, relative humidity, and rainfall, and to enable comparison of the contrasting influence of relative humidity (RH%) and rainfall on ambient delicate particulate matter ($PM_{2.5}$) concentrations between the three locations.

(a) (b) (c) (d)

Figure 2: Map of Thailand. (a) Map of Nakhon Si Thammarat, (b) Map of Walailak University, Nakhon Si Thammarat, (c) Map of Houses near Walailak University, and (d) Map of the village in Tha Sala District.

2-2- Sensor PM Low Cost and Davis AirLink

The Plantower Laser $PM_{2.5}$ dust sensor, PMS 3003, was a low-cost ($15 USD) commercially available laser particle sensor. This sensor was used to measure $PM_{2.5}$ as part of a network of low-cost devices from Location Aware Sensing Systems. The sensor's effective measurement range is 0-500 $\mu g/m^3$, with a resolution of 1 $\mu g/m^3$. The working conditions (DHT22 High Accuracy Digital Temperature and Humidity Sensor) of the sensors are -40 to 80 ◦C and 0-100%, characteristics which are suitable for measuring the $PM_{2.5}$ in ambient air in Southern Thailand. A Plantower Laser $PM_{2.5}$ dust sensor and an ESP32 NodeMCU were integrated to form a low-cost (<$100) sensor, as illustrated in **Figure 3a.** Data from two of these low-cost sensors were compared with those obtained using a reference method with a Davis AirLink (AEM, USA) **(Figure 3b).** The Davis AirLink was situated at Walailak University, on the ground floor of the Center of Excellence for Ecoinformatics, in the Innovative Building Parking Lot.

(a) (b)

Figure 3. (a) Plantower Laser $PM_{2.5}$ dust sensor PMS3003 with IoT and (b) Davis AirLink station installed at one of our study locations.

2-3- Collecting data

The data collection phase was conducted with meticulous precision to generate a robust dataset that supports the comparative analysis of $PM_{2.5}$ sensitivity to relative humidity (RH%) and rainfall. The study was strategically focused on capturing spatial variations across three distinct environmental contexts within Nakhon Si Thammarat Province: Educational Zone (Walailak University), representing a zone with moderate, localized emissions and controlled open space. Urban Zone (High-Density Houses): Characterized by high population density and localized traffic/residential emission sources.Suburban/Rural Zone (Tha Sala District Villages): Representing a lower-density environment dominated by regional or agricultural emissions. Monitoring Period and Instrumentation: Our data collection commenced with the installation of Davis AirLink sensors (or equivalent instruments) at all three predetermined locations. The monitoring campaign was conducted for more than 30 days, from November 14 to December 14, 2025. This extended observation timeframe was essential for capturing a sufficient variety of meteorological conditions, including periods of high RH%, significant rainfall events, and dry periods, which are critical for isolating the influence of the target variables on $PM_{2.5}$ concentration. The sensors were configured to record high-resolution measurements of $PM_{2.5}$, relative humidity RH%, and rainfall (mm) at five-minute intervals. The data was continuously streamed and retrieved via the DavisNet cloud service. This 5-minute temporal resolution ensured that detailed changes in $PM_{2.5}$ associated with rapid meteorological shifts—such as the onset of a rainfall event or a rapid rise in RH% leading to hygroscopic growth—were accurately captured. Data Consistency and Reliability. The 30-day synchronized monitoring across the three sites provided comprehensive 24-hour datasets that were crucial for ensuring the reliability and statistical power of the results. This extended period enabled systematic assessment of the consistency of $PM_{2.5}$ measurements and the ecological reliability of the Davis AirLink system under highly variable environmental conditions (urban pollution versus rural background). Furthermore, the continuous retrieval of reference data from the DavisNet cloud service ensured data integrity and facilitated a comprehensive assessment of the system's operational behavior in diverse environments. The strategic collection approach ultimately yielded the necessary dataset for statistical analysis of how the effects of RH% (formation) and rainfall (removal) differ across the study zones' underlying environmental characteristics.

2-4- Data Analysis

A calibration curve algorithm was constructed using a 30-day sensor measurement dataset from Walailak University, a house near the university, and a village in Tha Sala. These datasets were analyzed to calibrate sensor performance under different environmental conditions. Two-way analysis of variance (ANOVA) was performed to compare the effects of relative humidity (RH%) and rainfall on ambient particulate matter ($PM_{2.5}$) concentrations across the three locations. Simultaneously, linear regression analysis was used to compare the contrasting effects of relative humidity (RH%) and rainfall on ambient particulate matter ($PM_{2.5}$) concentrations at Walailak University, a house near the university, and a village in Tha Sala. This method provides insight into the contrasting effects of relative humidity (RH%) and rainfall on ambient particulate matter ($PM_{2.5}$) concentrations across different environments.

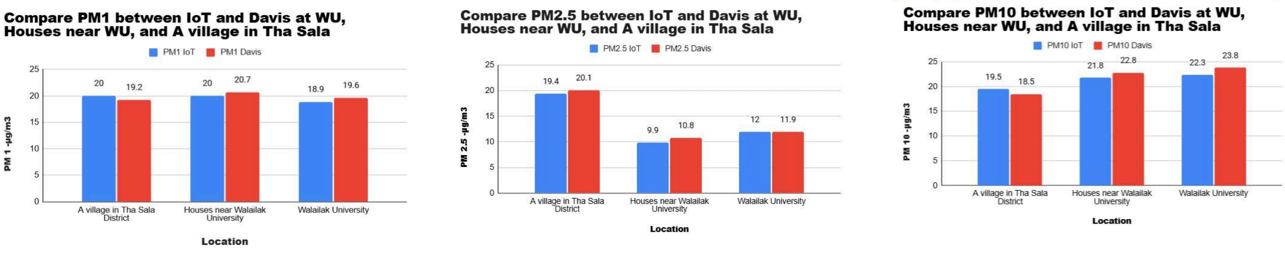
Figure 4. Cloud data was collected using the GLOBE Observer: Cloud application.

2.5 GLOBE Observer Application: Air temperature and Relative humidity

The GLOBE Atmosphere protocol (Cloud, air temperature, and relative humidity) was used to measure the atmosphere at three locations. We used the GLOBE Observer Cloud application to collect cloud data, specifically the percentage of cloud cover, cloud type, sky clarity, and sky color, to correlate it with atmospheric $PM_{2.5}$ levels. The data collection began with sensors installed at three locations: Krasaew Dam, Thasala, and Walailak University in Nakhon Si Thammarat Province. Data collection took place from November 15 to December 15, 2025, at all three locations: Walailak University, a house near the university, and a village in Tha Sala. Both instruments recorded high-resolution data from Davis AirLink over the same period. This reference data was extracted from the Davis Net cloud service, which stores readings at 5-minute intervals, yielding a 24-hour dataset.

3. Results and Discussion

3.1 Comparison of PM $_{2.5}$ values of each location using IoT PM sensor and Davis AirLink.



(a) (b) (c)

Figure 5: Comparison of (a) PM_1, (b)$PM_{2.5}$, and (c)PM_{10}: IoT Sensor vs. Davis Instrument at Three Locations

The comparison of three particulate matter types (PM_1, $PM_{2.5}$, PM_{10}) measured by the IoT Sensor System against the standard Davis Instrument across three locations yielded the following:PM_1: Values were the closest across all locations (ranging from approximately 19-21 mg/m³). This suggests high accuracy of the IoT sensor in measuring wonderful particles.$PM_{2.5}$: Davis values were slightly higher than IoT in all spots (peaking at about 20 mg/m³ in Tha Sala), but the overall trend was consistent. The readings at Walailak University were the most similar (11.9 vs 12).PM_{10}: Davis values were notably higher than IoT readings, particularly for PM_1 and $PM_{2.5}$(peaking at approximately 23 mg/m^3 at Walailak University). This indicates that the IoT sensor might have slightly lower accuracy in measuring the larger particles (PM_{10}).Conclusion: Overall, the IoT sensor system yields results that are consistent with, and close to, those of the standard Davis instrument across all parameters (especially PM_1), supporting its practical use for air quality monitoring.

3.2 Comparison of $PM_{2.5}$ values and rainfall

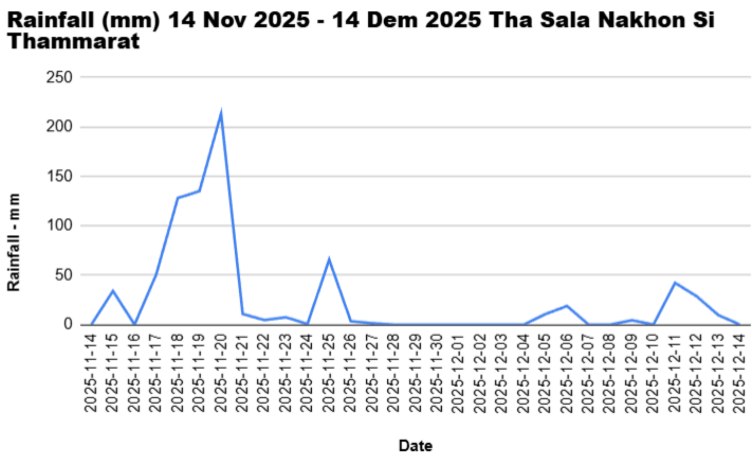


Figure 6: Rainfall

Between November 14 and December 14, 2025, the Tha Sala area of Nakhon Si Thammarat experienced highly variable weather conditions, particularly toward the end of November.

The graph shows that the peak rainfall during this period occurred severely on November 20, 2025, with precipitation exceeding 200 millimeters. This level is classified as Very Heavy Rain, posing a high risk of flooding. Slightly earlier, on November 18 and 19, the area also received heavy rainfall, with approximately 120-130 mm. This sustained high rainfall volume indicates a potential for flash floods.

Following the severe downpour on November 20, rainfall volume rapidly decreased and remained low. It then surged again to a "Heavy Rain" level of approximately 65 millimeters on November 25, before the rain largely stopped for almost a week, from November 27 into early December.

In early December, most rainfall was light to moderate, with minor increases between December 5-6 and a slight spike on December 11-13. However, this did not reach the "Heavy Rain" level seen in November. Overall, rainfall severity was concentrated in mid-to-late November, with a peak exceeding 200 mm, the month's most prominent event.

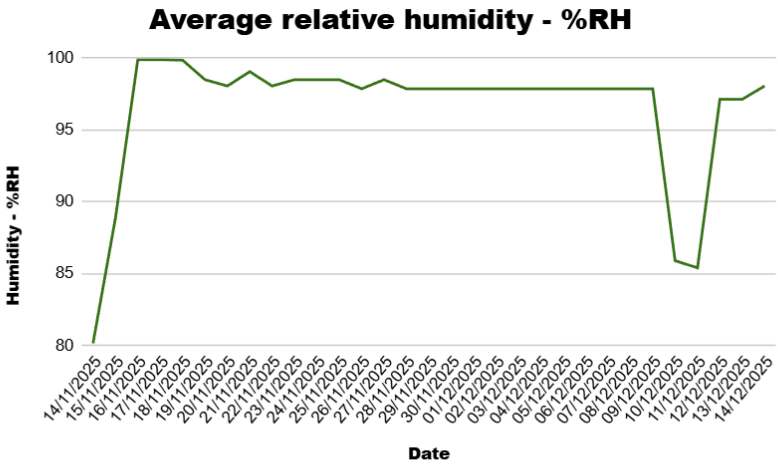


Figure 7: Average of Humidity

The average humidity graph (**Figure 7**) for November 14 to December 14, 2022, indicates that most of the period was characterized by high to very high humidity. At the beginning (November 14-17), humidity increased rapidly from approximately 80% to 100%, and it remained at this high level (approximately 98%-100%) throughout mid to late November. After November 22, humidity recovered and remained very high, at approximately 98%, with little change through early December (until December 10), despite minimal or no rainfall during this period. The most notable point is the rapid drop in humidity during December 11-12, which reached a low of approximately 85%, marking the driest period on record. Subsequently, humidity rapidly increased again to a high level (approximately 97%) on December 13-14. Overall summary: The air was very humid for almost the entire period. There was only a brief period on December 11-12 when the humidity dropped significantly.

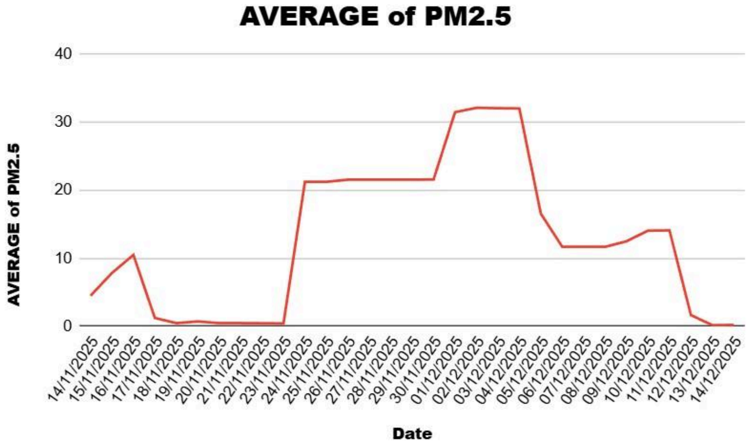
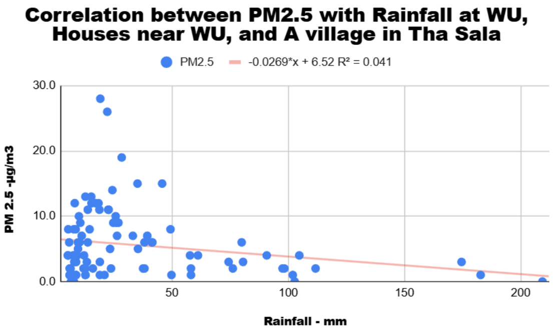


Figure 8: Average of PM $_{2.5}$

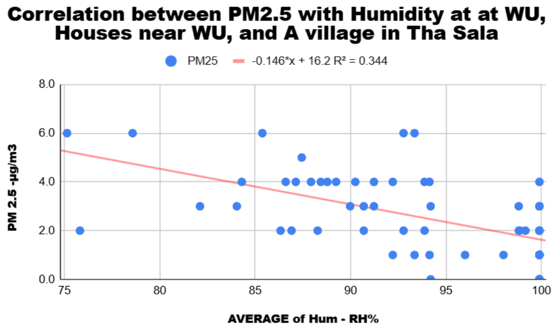
The graph displays the average $PM_{2.5}$ values from November 14, 2025, to December 14, 2025(**Figure 8**). The key trends can be summarized as follows: Low Value Periods (17 Nov - Nov 24 and Dec 13 - Dec 14): In the initial period between November 17 and November 24, $PM_{2.5}$ values were very low and stable (near zero). The values returned to this low level again towards the end of the graph, on December 13-14. Moderate Value Periods (Nov 25 - Dec 01 and Dec 06 - Dec 12): After November 24, the value spiked rapidly to approximately 21-22 micrograms per cubic meter (mg/m³) and remained stable at this level until December 1. Following the sharp drop on December 6, the value increased slightly and fluctuated between approximately 11 and 14 mg/m³ from December 7 to December 12.Peak Value Period (Dec 02 - Dec 05): There was a significant, rapid increase on December 2, peaking at approximately 32 mg/m³.The value remained stable at this high level for 4 days, until December 5, when it dropped sharply on December 6. Overall, the graph clearly shows the volatility of $PM_{2.5}$ levels, with rapid spikes and plateaus before returning to very low levels at the end of the observed period.

3.3 Comparison of $PM_{2.5}$ values and rainfall in each location

This figure shows the highest $PM_{2.5}$ concentration during the first week of December. At the same time, during the mentioned month, $PM_{2.5}$ concentrations ranged from 20 to 75 μg/m³, exceeding the WHO guideline value of 15 μg/m³. Despite rainfall observed in mid-December, $PM_{2.5}$ concentrations in Bangkok did not change significantly, despite rain being known for its air-purifying effects. This implies that several human and environmental factors, such as traffic emissions, industrial activities, and weather conditions, can cause air pollution to surge. Therefore, a single rainfall event cannot rapidly reduce $PM_{2.5}$ concentrations, especially during the dry season.



(a)



(b)

Figure 9: Correlation between $PM_{2.5}$ and Atmospheric Moisture (rainfall and relative humidity)

Correlation between $PM_{2.5}$ and Atmospheric Moisture. The analysis of the relationship between $PM_{2.5}$ concentration and atmospheric moisture (rainfall and relative humidity) across the three study areas leads to the following conclusions. $PM_{2.5}$ and Rainfall Relationship. Results: A negative correlation was observed between $PM_{2.5}$ concentration and daily rainfall.Statistical Metrics: Slope (m) = -0.0209; Coefficient of Determination (R^2) = 0.041 (Low). This indicates that as rainfall increases, $PM_{2.5}$ tends to decrease. However, the low R^2 indicates that rainfall accounts for only 4.1% of the variability in $PM_{2.5}$. Discussion (Wet Deposition): This result aligns with the principle of wet deposition, whereby rainfall effectively scavenges and washes out $PM_{2.5}$ particles from the atmosphere. The low R^2indicates that wet deposition is not the sole or dominant factor controlling $PM_{2.5}$ levels. High data variability, particularly where $PM_{2.5}$ remains high despite low-to-moderate rainfall, suggests that the scavenging efficiency is highly dependent on rain intensity/duration and the continuous presence of strong local emission sources (e.g., traffic, nearby industrial activities).2. $PM_{2.5}$ and Relative Humidity (RH) RelationshipResults: A stronger negative correlation was found between $PM_{2.5}$ concentration and average relative humidity (RH%). Statistical Metrics: Slope (m) = -0.146; Coefficient of Determination (R^2) = 0.344 (Significantly higher than rainfall). Relative humidity accounts for approximately 34.4% of $PM_{2.5}$ variability, indicating a relatively consistent influence. Discussion (Deposition Mechanism): The clear negative correlation suggests that, within the high-RH range (mostly 80% to 100%) observed in the study area, the removal effect of high humidity dominates over any potential formation/growth effects.Dominant Mechanism: When RH is very high (approaching 100%), $PM_{2.5}$ particles undergo significant Hygroscopic Growth. This dramatically increases the particle size and mass, accelerating Gravitational Settling (Dry Deposition) to the surface, thereby effectively reducing airborne concentration 3. A comparative study of conclusions demonstrates that both rainfall and relative humidity are negatively correlated with $PM_{2.5}$, thereby contributing to pollution reduction. However, Relative Humidity exhibits a significantly stronger and more consistent correlation (R^2 = 0.344) with $PM_{2.5}$ variability than rainfall (R^2 = 0.041). This suggests that in high-humidity environments (such as Nakhon Si Thammarat Province), the Dry Deposition mechanism, enhanced by high RH, is likely the major and more consistent factor controlling $PM_{2.5}$ levels, compared with the intermittent scavenging effect of rainfall.

4. Conclusion

This study analyzed the complex and differential relationships between atmospheric moisture factors (rainfall and relative humidity) and ambient $PM_{2.5}$ concentrations across diverse geographic and environmental settings in Nakhon Si Thammarat Province. Relationship with Rainfall: The study confirmed a negative correlation between rainfall and $PM_{2.5}$, supporting the principle of Wet Deposition as a natural cleansing mechanism that removes particles from the air3. However, the low Coefficient of Determination (R^2) of 0.041 indicates that rainfall accounts for only a small percentage of $PM_{2.5}$ variability, suggesting its explanatory power is limited by rainfall intensity/duration and the continuous presence of strong local emission sources Relationship with Relative Humidity (RH%): A significantly stronger and more consistent negative correlation was found, with an R^2 value of 0.3448. In the high-RH range (mostly 80% to 100%), the dominant $PM_{2.5}$ reduction mechanism is Dry Deposition 10. This is accelerated by the significant Hygroscopic Growth of particles, which increases their size and mass. Comparative Summary: In the high-humidity environment of the study area, Relative Humidity plays a more critical and consistent role in controlling $PM_{2.5}$ levels via the deposition mechanism, compared with the intermittent scavenging effect of rainfall. This research enhances understanding of the current air quality situation and provides essential, site-specific information to inform the development of programs and policies that support accurate $PM_{2.5}$ forecasting and management.

I would like to claim IVSS badges

1. **I make an impact**

The report clearly describes how a local issue gave rise to the research questions or connects local and global impacts. The students must clearly explain or show how the research positively impacted their community by making recommendations or taking action based on findings. This study indicates that particulate matter ($PM_{2.5}$) is an air pollutant that affects human health. $PM_{2.5}$ can travel deeply into the respiratory tract, reaching the lungs. Exposure to fine particles can cause short-term health effects, including eye, nose, and throat irritation; coughing; sneezing; runny nose; and shortness of breath.

2. **I am a STEM professional.**

The report clearly describes the collaboration with a STEM professional that enhanced research methods, improved precision, and supported more sophisticated analyses and interpretations of results. The sensor data were used to analyze the results. Use the graph to see how the data relate.

3. **I am a data scientist.**

The report thoroughly examines the students' proprietary data and additional data sources. Students critically evaluate the limitations of these data, draw inferences about historical, current, or future events, and leverage the data to address questions or resolve issues within the depicted system. This may involve incorporating data from other educational institutions or utilizing information from external databases. We developed a $PM_{2.5}$ sensor to collect data and compare its performance with that of commercially available sensors.

Acknowledgments

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