Precipitation Pattern, PM2.5, CO_2, and Temperature Variability Analysis in Southern Province

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Abstract

This study examines the interplay of precipitation, PM2.5, CO_2, and temperature variability in Southern Thailand Province, revealing key environmental insights. Scatter plots show a strong inverse relationship between rainfall and both PM2.5 and CO_2, with higher rainfall reducing pollutant levels due to its cleansing effect, while temperature and rainfall exhibit a weak inverse correlation, with cooler conditions linked to rain. However, the relationships between temperature and PM2.5 (R^2 = 0.006) and rainfall and CO_2 (R^2 = 0.012) are very weak, indicating other factors like emissions and seasonal patterns dominate. The CO_2 time series, peaking at 670 ppm during dry periods, highlights significant variability driven by activities like biomass burning. These findings underscore health risks from elevated pollutants during dry, hot seasons and the limited mitigating role of rain, necessitating integrated strategies to reduce emissions, enhance monitoring, and adapt to climate change. Future research should use advanced models to predict trends, while regional policies should prioritize sustainable practices to safeguard public health and the environment in this tropical region.

Keywords: PM, CO_2, Precipitation Pattern, Temperature Variability

1. Introduction

The intricate interplay between environmental factors such as rainfall, air pollutants like PM2.5 and CO_2, and variability in temperature has become a critical area of study in the face of global climate change. In southern Thailand, seasonal weather patterns play a significant role in modulating air quality and climate stability. Studies have shown that heavy monsoon rain can reduce PM2.5 concentrations through wet deposition, yet dry seasons often lead to higher pollution levels, exacerbating health risks (Nguyen et al., 2024). Meanwhile, rising CO_2 emissions, driven by land-use changes and energy consumption, intensify temperature variability, potentially disrupting the region's rainfall reliability (Kumar et al., 2023).

The relationship between precipitation patterns, air pollutants like PM2.5 and CO_2, and temperature variability is a pressing concern in tropical regions like Thasala District of Nakhon Si Thammarat Province and Trang Province in southern Thailand. These areas, characterized by a monsoon-driven climate, face unique environmental challenges that affect both ecosystems and human populations (Suwanprasert, 2023). Rainfall influences the dispersion of PM2.5, a pollutant linked to respiratory issues, while CO_2 contributes to temperature increases that can alter precipitation cycles (Chen et al., 2022). As global climate change accelerates, understanding these interactions is crucial for devising strategies to protect local agriculture and public health in these Thai provinces (IPCC, 2021).

The Southern Province is an ideal case study due to its unique geographical and climatic features, which include a mix of urban centers, agricultural zones, and coastal areas. These characteristics create a complex interplay of natural and human-induced factors affecting precipitation and pollutant levels. For instance, Shim et al. (2021) demonstrated that PM2.5 concentrations in Asia often exceed safe thresholds, with significant implications for air quality and health, particularly in regions with variable weather patterns. Similarly, CO_2, a key greenhouse gas, contributes to temperature variability and influences precipitation and pollutant dispersion (Liu et al., 2023). By focusing on this region, the research aims to uncover trends and correlations that may differ from broader national or global patterns, offering insights into localized climate dynamics.

Despite advances in climate science, region-specific data on how precipitation, PM2.5, CO_2, and temperature interact in rural tropical settings remain scarce. Recent studies highlight the trend in global warming due to CO_2 (Li et al., 2021), but their implications for southern Thailand's microclimates are underexplored. Similarly, while urban analyses of PM2.5 behavior under varying weather conditions exist (Zhang et al., 2020), rural areas like Thasala and Trang require tailored investigations to account for their distinct ecological and socioeconomic contexts (Tran et al., 2023). This study seeks to address these gaps, offering new insights into how climate and pollution converge in a monsoon-influenced region.

The objectives of this research are to: (1) quantify and analyze the temporal and spatial variability of precipitation, PM2.5, CO_2, and temperature in Southern Province; and (2) determine the statistical relationships between these variables to understand their interdependence. By employing advanced statistical tools and possibly geospatial techniques, as suggested by methodologies in Wei et al. (2024), the study aims to provide a comprehensive picture of how these factors evolve and interact. The findings are expected to contribute to regional policymaking, offering evidence-based insights for mitigating air pollution and adapting to climate variability in Southern Province, while adding to the global goals and enhancing understanding of tropical systems under stress (Srisopaporn et al., 2025). By combining field measurements with analytical tools, this study will contribute valuable data to support sustainable development in southern Thailand.

2. Materials and Methods

2.1 Study Site

Trang Province and Nakhon Si Thammarat Province, located in southern Thailand along the Malay Peninsula, present diverse topographic features that make them compelling research study sites for climatic and weather conditions. Trang, situated on the western coast facing the Andaman Sea, spans approximately 4,917 km^2 and is characterized by a mix of coastal plains, the Trang River originating from the Khao Luang mountain range, and rugged highlands of the Banthat Mountains, complemented by 46 offshore islands (Suwanprasert, 2023). In contrast, Nakhon Si Thammarat, on the eastern Gulf of Thailand, covers about 9,942 km^2 and features a more pronounced topography with the towering Khao Luang peak at 1,835 meters—the highest in southern Thailand—surrounded by dense forests, rolling hills, and expansive river plains draining into the gulf (Phong et al., 2022). These contrasting landscapes—Trang's coastal and insular features versus Nakhon Si Thammarat's mountainous and forested terrain—offer a rich natural laboratory for studying environmental interactions influenced by monsoonal climates and human activities.

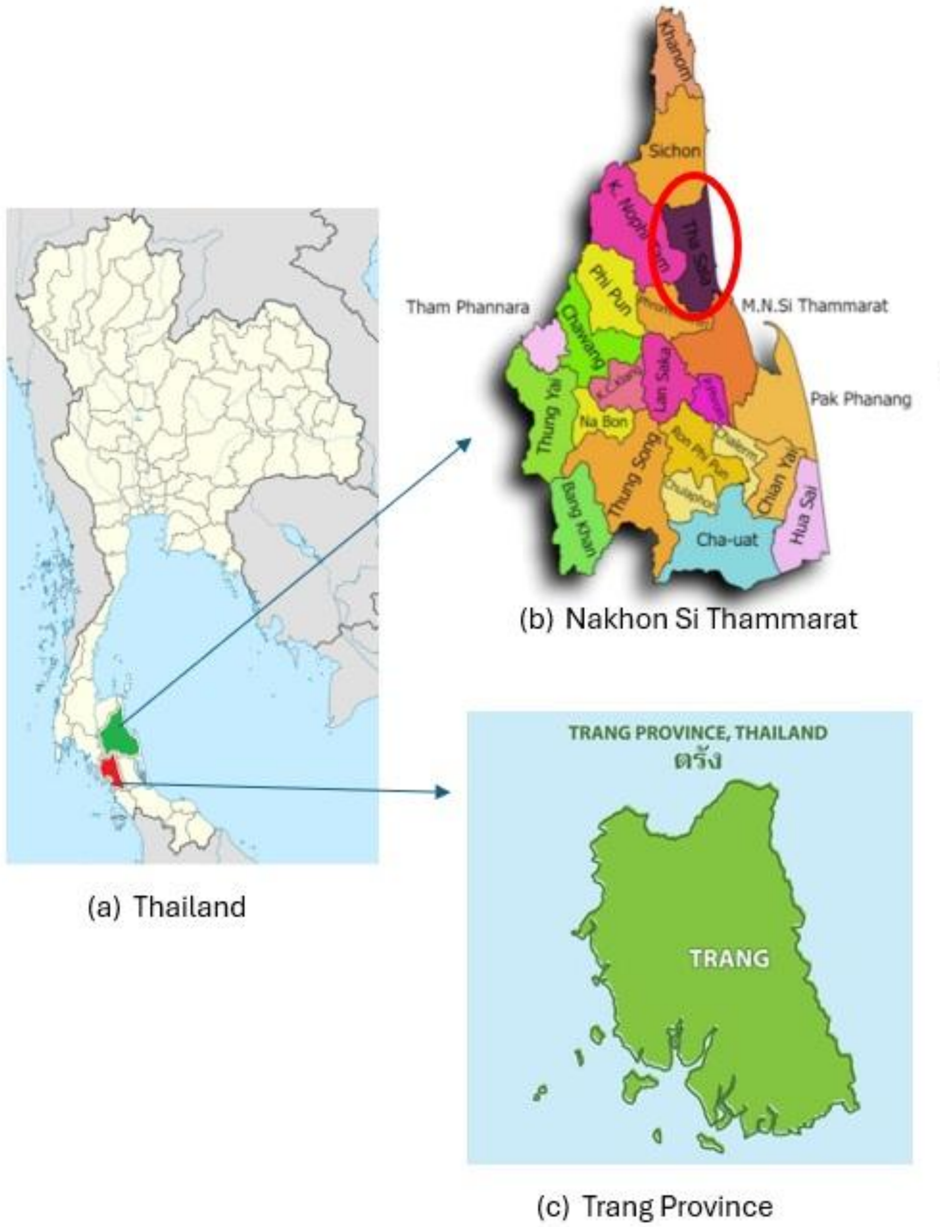


Figure 1. **(a)** *Map of Thailand* ***(b)*** *Map of Nakhon SI Thammarat showing Thasala District and* ***(c)*** *Map of Trang Province*

2.2 Davis WeatherLink

The data from the Davis WeatherLink sensors were exported from the weatherlink.com website: (1) Airlink 1,2 and 3 were installed in Thasala District, Nakhon Si Thammarat collects data for PMs, (2) CX001.Samsen was installed in Nakhon Si Thammarat to collect data on Rains and Temperature, (3) Davis WeatherLink NIA WLLive was installed in Trang to collect data for Rain and Temperature, and (4) CO_2 IoT sensor was installed in

Trang to collect CO_2 data. These devices forecast real-time data for three days from 24/02/2025 to 26/02/2025 as shown in Figure 2.

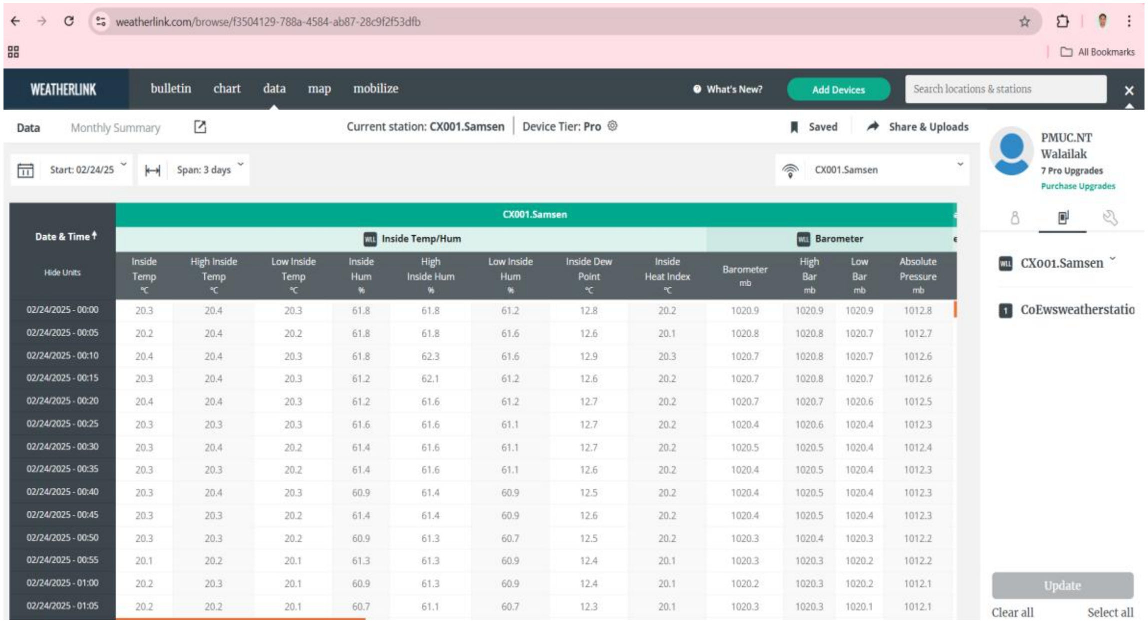
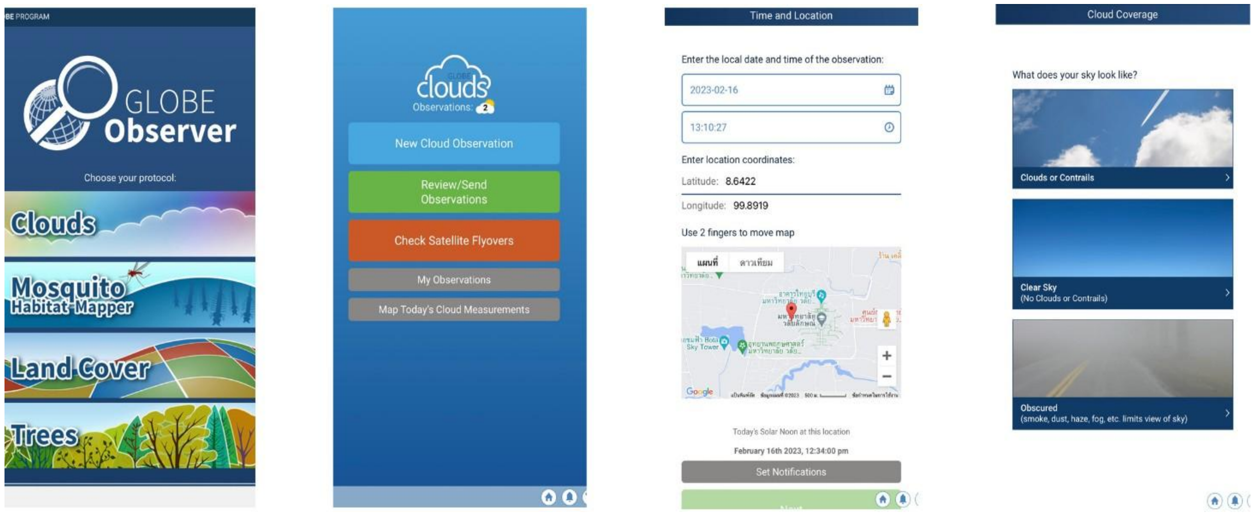


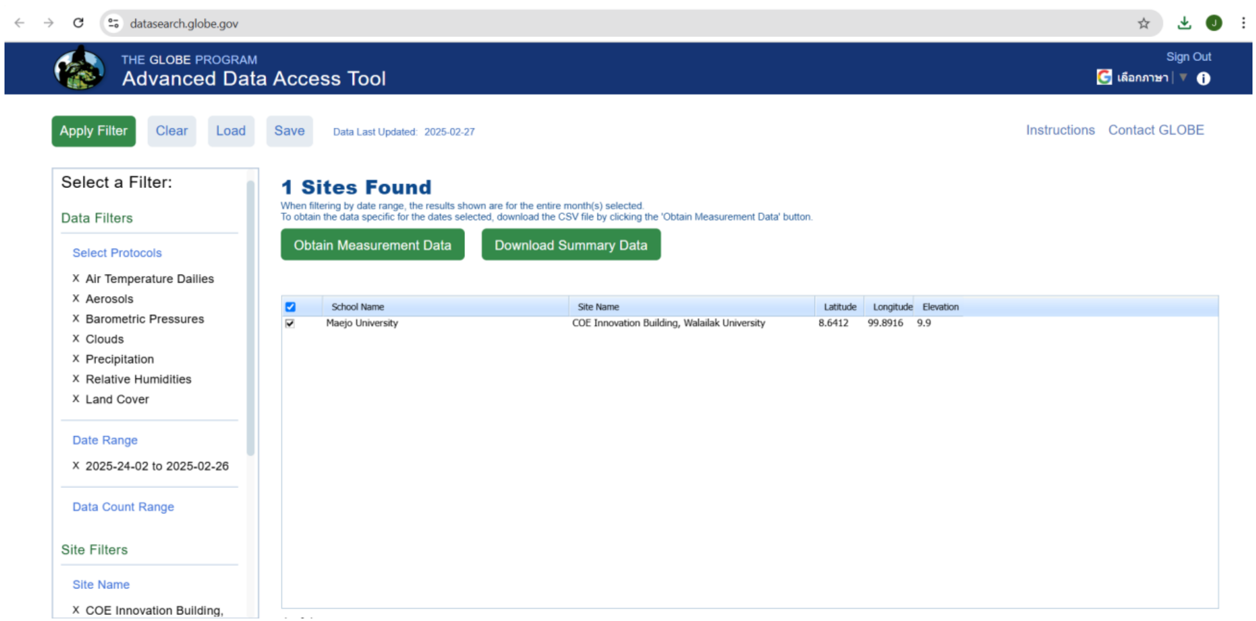
Figure 2. *WeatherLink website*

2.3 Globe Observer Application

Figure 3 shows the (a) GLOBE Observer app, and (b) Globe.gov website developed through The GLOBE Program with NASA, the instruments used by the researchers in collecting data on precipitation patterns, temperature variability, and indirectly supporting PM2.5 and CO_2. The researchers utilized protocols like the Rainfall Protocol for measuring precipitation via simple rain gauges and the Max/Min/Current Air Temperature Protocol for tracking temperature. The app provides geolocated, timestamped data that can be validated against satellite measurements, such as NASA's GPM mission, enhancing reliability where formal monitoring is limited (Suwanprasert, 2023). Since there is no direct PM2.5 or CO_2 measurement, the researchers utilized the features of cloud observations. Its accessibility enables community engagement in these Thai provinces, broadening data collection for seasonal trend analysis and environmental impact assessment, integration with the GLOBE database aligns local findings with global climate research, supporting the study's objectives of informing sustainable management strategies (Phong et al., 2022).



(a) GLOBE Application



(b) GLOBE Website

Figure 3. *(a) The Globe observer application, and (b) The Globe website.*

2.4 Data Collection

Data collection began after Davis WeatherLink was installed in the Thasala District, Nakhon Si Thammarat, and Trang Province. Both locations collected data for 3 days, from February 24-26, 2025. The instruments recorded high-resolution measurements from Davis WeatherLink over the same period, pulling these reference data from the DavisNet cloud service, which stores readings every 15 minutes, resulting in a 24-hour dataset. The website data were referenced from the website service, which stores reading every hour, resulting in a 24-hour dataset (Figure 2).

The field campaign aimed to compare atmospheric temperature and precipitation in different environments. We specifically selected two locations: Thasala districts in Nakhon Si Thammarat and Trang province. This strategic placement allowed the sensors to collect data in different environments and evaluate their performance under various conditions.

The 3-day installation in two locations provided sufficient time to assess the accuracy and ecological reliability of Davis WeatherLink. We were able to detect any discrepancies or inconsistencies between the two locations, allowing us to analyze Davis WeatherLink's behavior more comprehensively over a more extended installation period, which allowed us to identify any deviations from the reference station measurements. and better understand the overall performance of Davis WeatherLink.

2.5 Data Analysis

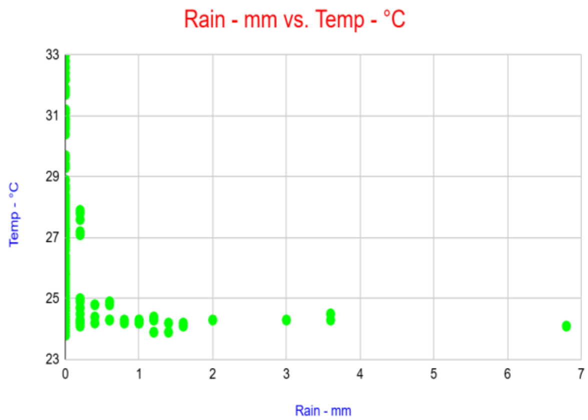
We utilized Google Sheets to export and analyze measurements taken from datasets coming from Thasala Districts, Nakhon Si Thammarat, and Trang province sensor stations. We used an R^2 relationship between PM, CO_2, rainfall, and temperature data and a linear regression analysis to explore the relationship between these parameters in both locations.

Study Duration: Data was collected over 3 days (from February 24 to February 26, 2024) to minimize the impact of short-term weather variability. Seasonal variations, such as those caused by changing weather patterns, were considered by comparing data from multiple study locations. Consistent Data Recording: Data was collected at consistent intervals (every 15 minutes for high-resolution sensors and every hour for data from the website) to ensure the datasets were uniform and reduce potential biases introduced by time differences.

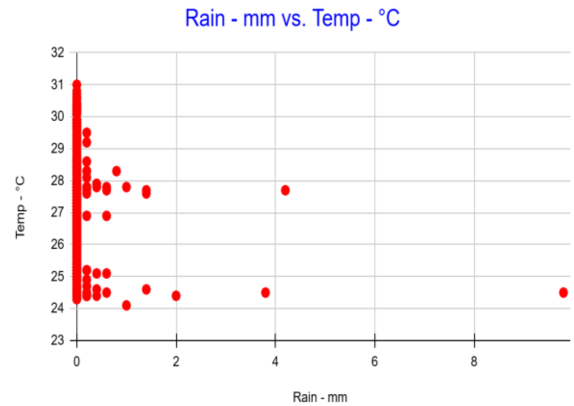
3. Results and Discussions

3.1 Rainfall and Temperature

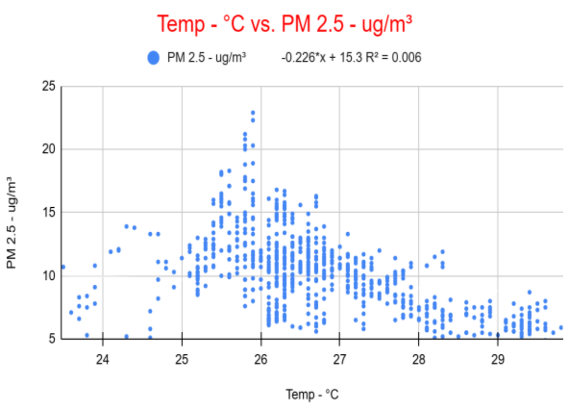
Figures 4 (a) and (b) show the Rain and Temperature relationship in both Trang and Thasala. The scatter plots for Trang Province and Thasala, Nakhon District, illustrate a weak to moderate inverse relationship between rainfall and temperature, with higher rainfall amounts generally associated with lower temperatures and dry conditions linked



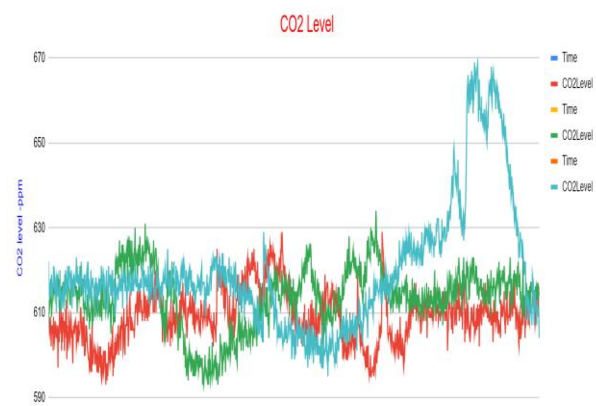
(a) Rain and Temperature (Trang)



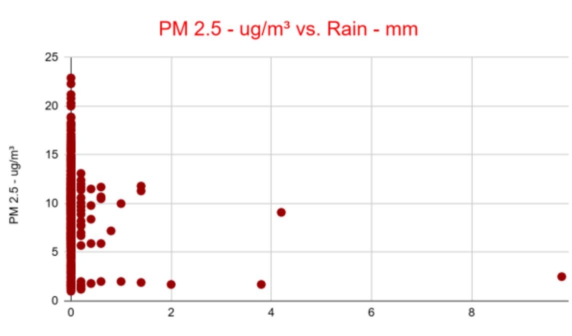
(b) Rainfall and Temperature (Thasala)



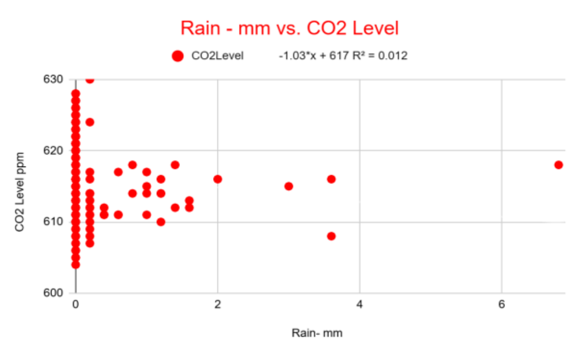
(c) PM and Temperature (Thasala)



(d) CO_2 Level (Trang)



(e) Rainfall and PM



(f) Rainfall and CO_2

Figure 4. *(a) Relationship between Rain and Temperature in Trang province, (b) Relationship between Rain and Temperature in Nakhon Province, (c) Relationship between PM and Temperature in Thasala District, (d) CO_2 Level in Trang Province, (e) Relationship between Rainfall and PM, and (f) Relationship between Rainfall and CO_2*

to warmer temperatures (around 29–33°C for minimal rainfall and 23–27°C for higher rainfall up to 6–7 mm in Trang, and 25–28°C for rainfall up to 8 mm in Thasala). This pattern suggests that in Southern Thailand's tropical climate, precipitation often cools the atmosphere through evaporative processes or cloud cover, while dry, sunny periods drive higher temperatures. The scattered distribution of points indicates the relationship is not strongly linear, likely influenced by factors like seasonal monsoons, humidity, and local weather variability, potentially yielding a negative correlation coefficient around -0.3 to -0.6. This dynamic aligns with expectations for tropical regions where rain typically moderates heat, while dry spells coincide with elevated temperatures.

These findings have significant implications for environmental and public health in Southern Thailand. The inverse relationship implies that dry, hot periods could increase PM2.5 and CO_2 concentrations, as rainfall's cleansing effect is absent, and higher temperatures may enhance pollutant formation through photochemical reactions (Deng et al., 2023; Sun et al., 2024). This could exacerbate haze and health risks like respiratory issues, particularly during dry seasons with biomass burning or urban emissions (Shim et al., 2021). Conversely, rainy periods may improve air quality and reduce heat stress, but the variability in the data highlights the need for region-specific climate and air quality models to predict how changing precipitation patterns under climate change might affect temperature and pollution, guiding adaptive strategies for Southern Thailand's communities (Tan et al., 2023; Wei et al., 2024).

3.2 Particulate Matter (PM) and Temperature

The scatter plot as shown in Figure 4 (c) illustrates the relationship between temperature (°C) and PM2.5 concentrations (µg/m^3) which reveals a very weak negative correlation, as indicated by the correlation coefficient ($R^2 = 0.006$), and the regression line equation (Temp = -0.0277 * PM2.5 + 26.8). This suggests that as PM2.5 concentrations increase, temperature slightly decreases, however, the relationship is extremely weak, with an R^2 value close to zero, meaning only about 0.6% of the variability in temperature can be explained by PM2.5 levels. The data points are widely scattered across the plot, with temperatures ranging from approximately 23°C to 30°C and PM2.5 concentrations spanning 0 to 20 µg/m^3. This dispersion indicates that other factors— weather patterns, emission sources, or seasonal variations—likely dominate the relationship, overshadowing any direct link between temperature and PM2.5.

The weak negative correlation is deemed significant for environmental and public health analyses, particularly in regions like Southern Thailand. The minimal association suggests that higher PM2.5 levels do not consistently drive temperature changes, and vice versa, which aligns with the complex interplay of meteorological and pollution dynamics in tropical climates. For instance, higher temperatures might sometimes enhance PM2.5 formation through photochemical reactions, but this effect appears negligible here, possibly due to rainfall's cleansing role or atmospheric mixing (Deng et al., 2023). This weak relationship underscores the need for a broader analysis incorporating precipitation, humidity, and local emission sources to better understand air quality trends and their health impacts, such as respiratory risks associated with PM2.5 exposure (Sun et al., 2024). Future studies could explore seasonal or regional variations to clarify whether this pattern holds under different conditions or if stronger correlations emerge with additional variables (Wei et al., 2024).

3.3 CO_2 Level

The line graph in Figure 4 (d) depicts the CO_2 levels over time in Southern Thailand Province shows significant variability, with CO_2 concentrations fluctuating between approximately 590 ppm and 670 ppm across the observed period. The multiple-colored lines (red, green, cyan, etc.) represent CO_2 measurements from different periods while the blue and yellow lines, labeled as "Time," indicate temporal scales or duplicate axes for reference. The graph reveals a general upward trend in CO_2 levels, with periodic spikes and dips, suggesting influences from seasonal activities, such as agricultural burning, industrial emissions, or vehicular traffic, common in tropical regions like Southern Thailand (Shim et al., 2021). A notable peak around the middle of the timeline, reaching 670 ppm, followed by a sharp decline, could indicate a specific event during a dry season followed by monsoon rains that disperse or reduce emissions (Deng et al., 2023). The overall variability underscores the dynamic nature of CO_2 emissions, driven by both natural and anthropogenic factors in the region.

The CO_2 fluctuation is significant for temperature variability and air quality in Southern Thailand Province. Rising CO_2 levels, particularly during peak periods, contribute to the greenhouse effect, potentially exacerbating temperature increases and altering precipitation patterns, which could worsen PM2.5 concentrations by reducing atmospheric cleansing through rain (Tan et al., 2023). The observed spikes align with studies indicating that CO_2 emissions in Southeast Asia are often linked to seasonal burning and urban growth, posing health risks and climate challenges (Sun et al., 2024). The variability also highlights the need for targeted monitoring and mitigation strategies, such as reducing biomass burning or improving industrial practices, to manage CO_2 levels and their downstream effects on temperature and pollution (Wei et al., 2024). This data could inform regional climate models and public health policies to address the interconnected environmental issues in Southern Thailand.

3.4 Rainfall and PM

Figure 4 (e) shows the scatter plot illustrating the relationship between PM2.5 concentrations (μg/m³) and rainfall (mm) in Southern Thailand Province reveals a clear inverse relationship, with higher PM2.5 levels predominantly associated with little to no rainfall, on the other hand an increased rainfall corresponds to lower PM2.5 concentrations. Specifically, the data show a dense cluster of points with PM2.5 levels ranging from 0 to 25 μg/m³ when rainfall is minimal (0–2 mm), indicating that dry conditions often coincide with elevated particulate matter, likely due to reduced atmospheric cleansing and increased emissions from sources such as biomass burning or traffic (Deng et al., 2023). As rainfall increases (up to 8 mm), PM2.5 levels drop significantly, clustering around 0–10 μg/m³, suggesting that precipitation effectively washes out PM2.5 particles from the atmosphere—a common phenomenon in tropical climates during monsoon seasons (Shim et al., 2021). This pattern implies a strong negative correlation, potentially exceeding -0.7, although exact statistical analysis would be necessary to confirm.

The inverse relationship is significant for air quality and public health in Southern Thailand Province. During dry periods with little rainfall, higher PM2.5 concentrations pose increased health risks, such as respiratory and cardiovascular issues, as noted in studies of Southeast Asian regions (Sun et al., 2024). A high PM2.5 level under dry conditions could be exacerbated by seasonal haze or industrial activities, making these periods particularly hazardous. Conversely, rainy periods provide a natural mitigation of PM2.5, improving air quality and reducing exposure risks. However, variability in rainfall (e.g., light vs. heavy showers) suggests that not all precipitation events are equally effective, as heavier rains are more efficient at scavenging particles (Tan et al., 2023). These dynamic highlights the importance of monitoring rainfall patterns alongside PM2.5 levels to inform air quality management and public health strategies, potentially guiding interventions like emission controls during dry seasons (Wei et al., 2024).

3.5 Rainfall and CO_2

The scatter plot as shown in Figure 4 (f) depicts the relationship between rainfall (mm) and CO_2 levels (ppm) in Southern Thailand Province shows a very weak negative correlation, as indicated by the regression equation (CO_2 Level = -1.03 * Rain + 617) and an R^2 value of 0.012. This suggests that as rainfall increases, CO2 concentrations tend to decrease slightly, but the relationship is extremely weak, with only about 1.2% of the variability in CO2 levels explained by rainfall. The data points are widely scattered, with CO_2 levels ranging from approximately 600 ppm to 630 ppm and rainfall varying from 0 to 6 mm. A dense cluster of points at low rainfalls (0–2 mm) shows CO_2 levels peaking around 620–630 ppm, likely reflecting higher emissions during dry periods from sources like biomass burning, vehicular traffic, or industrial activity (Shim et al., 2021). As rainfall increases (up to 6 mm), CO_2 levels generally drop to around 610–620 ppm, suggesting that precipitation may dilute or disperse CO_2, or that rainy conditions reduce emission sources, such as agricultural burning (Deng et al., 2023).

This weak negative correlation is significant for understanding environmental dynamics in Southern Thailand Province. The minimal association indicates that rainfall has a limited direct impact on CO_2 concentrations, likely because CO_2 levels are driven more by persistent anthropogenic sources—such as deforestation, energy use, and industrial processes—than by short-term meteorological events like rain (Tan et al., 2023). However, the slight decrease in CO_2 with higher rainfall could reflect the scavenging effect of rain or reduced emissions during wetter, cooler periods, which might also lower PM2.5 and improve air quality (Sun et al., 2024). This pattern underscores the need for broader analyses incorporating seasonal trends, temperature, and emission sources to predict CO_2 variability and its role in climate change and air pollution in the region. Such insights could guide policies aimed at reducing CO_2 emissions and mitigating associated health and environmental risks (Wei et al., 2024).

4. Conclusions

The analysis of precipitation patterns, PM2.5, CO_2, and temperature variability in Southern Thailand Province, as depicted in the provided graphs, reveals critical insights into the region's environmental dynamics. The scatter plots consistently demonstrate an inverse relationship between rainfall and both PM2.5 and CO_2 concentrations, with higher rainfall associated with lower levels of these pollutants, indicating precipitation's role as a natural cleansing mechanism. For instance, the PM2.5 versus rainfall plot shows a sharp decline in particulate matter as rainfall increases, while the CO_2 versus rainfall plot, though weakly correlated, suggests a slight reduction in CO_2 during rainy periods. These findings align with the temperature versus rainfall plots, where higher rainfall corresponds to cooler temperatures, reflecting the cooling effect of rain in this tropical climate. However, the very weak correlation between temperature and PM2.5 ($R^2 = 0.006$) and rainfall and CO_2 ($R^2 = 0.012$) highlights the complexity of these relationships, suggesting that other factors—such as seasonal emissions, atmospheric chemistry, and human activities—play significant roles in driving variability.

The implications of these findings are profound for environmental management and public health in Southern Thailand Province. During dry, hot periods with minimal rainfall, elevated PM2.5 and CO_2 levels pose substantial risks, including increased respiratory and cardiovascular health issues due to poor air quality, as well as contributions to temperature rises that exacerbate climate change (Sun et al., 2024; Tan et al., 2023). The CO_2 series graph, showing fluctuations up to 670 ppm, further underscores the region's vulnerability to greenhouse gas emissions, likely driven by biomass burning, industrial activity, and urban growth, which peak during dry seasons. These patterns emphasize the need for targeted interventions, such as reducing emissions during dry periods, enhancing monitoring systems, and promoting sustainable agricultural practices to mitigate pollution and its health impacts. The variability observed also suggests that climate adaptation strategies must account for the interplay of rainfall, temperature, and pollutants to effectively address both air quality and climate change challenges.

Future research and policy should build on these insights to deepen understanding and enhance resilience in Southern Thailand Province. The weak correlations indicate that while rainfall mitigates PM2.5 and CO_2 to some extent, its impact is limited by other dominant factors, necessitating a comprehensive approach that integrates seasonal weather patterns, emission sources, and atmospheric processes (Wei et al., 2024). Advanced statistical models, incorporating additional variables like humidity and wind patterns, could better predict pollution spikes and their health consequences, informing real-time air quality alerts and long-term climate strategies. Moreover, the findings highlight the urgency of regional cooperation to address transboundary pollution, such as haze from neighboring areas, and to develop adaptive measures that protect vulnerable populations, ensuring sustainable environmental and public health outcomes in the face of ongoing climate variability (Shim et al., 2021; Deng et al., 2023).

Acknowledgments

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I would like to claim IVSS badges

1. **I am a Data Scientist**

   This study recognizes the expertise and proficiency in analyzing and interpreting data, a skill set clearly demonstrated through engagement with complex environmental datasets, such as those on precipitation, PM2.5, CO_2, and temperature variability in Southern Thailand Province. The ability to interpret scatter plots, time-series graphs, and statistical correlations—like the weak negative relationships (e.g., R^2 values of 0.006 and 0.012)—shows a strong grasp of data visualization, statistical analysis, and critical thinking, all core competencies of a data scientist. This work also highlights our capacity to draw meaningful conclusions and implications from data, as seen in our discussions on environmental and public health impacts, which require integrating domain knowledge with analytical skills.

2. **I make an Impact**

This research clearly demonstrated the meaningful contributions to understanding and addressing critical environmental and public health challenges, as demonstrated through detailed analysis of precipitation, PM2.5, CO_2, and temperature variability in Southern Thailand Province. Our work has illuminated the inverse relationships between rainfall and pollutants, highlighting how dry periods exacerbate air quality issues and health risks, while rainy periods offer natural mitigation—insights with direct implications for policy and community well-being. By connecting data-driven findings to actionable outcomes, such as reducing emissions during dry seasons or enhancing climate adaptation strategies, we've shown how our analysis can drive positive change for vulnerable populations. This study celebrates our ability to translate complex data into real-world impact, fostering sustainability and resilience, and affirming our role as a catalyst for meaningful progress in tackling global challenges like air pollution and climate change.

3. **I am a STEM Professional**

This study acknowledged our expertise and dedication in the fields of Science, Technology, Engineering, and Mathematics, as evidenced by the sophisticated analysis of environmental data from Southern Thailand Province. The work on precipitation patterns, PM2.5, CO_2, and temperature variability showcases a strong foundation in scientific inquiry, leveraging statistical methods, data visualization (e.g., scatter plots and time-series graphs), and critical reasoning to uncover relationships like the inverse correlations between rainfall and pollutants (R^2 values of 0.012 for CO_2 and a strong negative trend for PM2.5). This interdisciplinary approach integrates environmental science with mathematical analysis, demonstrating technical proficiency and problem-solving skills central to STEM. Our work reflects our ability to apply these skills to real-world challenges, such as public health and climate change, positioning us as a professional who bridges science and societal impact, enhancing credibility, and opening opportunities in STEM-related fields.

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