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# Meteorological Influences on PM2.5 and PM10 Concentrations during Haze Periods in West Sumatra: A Case Study from May to July 2025

**Aditya Prapanca[1*], Muhammad Ansori Hasibuan[2]**

[1]Global Atmosphere Watch Bukit Kototabang, Indonesian Agency for Meteorology Climatology and Geophysics, Agam, Indonesia
[2]Climatology Station of Sumatera Utara, Indonesian Agency for Meteorology Climatology and Geophysics, Deli Serdang, Indonesia

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## Abstract

Forest and land fires during May–July 2025 in West Sumatra triggered haze events that significantly degraded air quality through increased concentrations of PM2.5 and PM10. This study aims to characterize the temporal variability of PM2.5 and PM10 and to assess the influence of meteorological parameters on particulate matter dynamics during the haze period. The results show a significant increase in PM2.5 and PM10 concentrations during the fire period, with fine particles dominating, as indicated by PM2.5/PM10 ratios exceeding 0.6. PM2.5 and PM10 exhibit a very strong positive cotpelation, suggesting common emission sources. Although most meteorological parameters display weak cotpelations with particulate concentrations, multivariate regression reveals that relative humidity and wind speed—particularly in the upper atmospheric layer—significantly influence PM variability. These findings indicate that meteorological conditions act as modulators of particulate concentrations, while forest fire emissions remain the primary driver of elevated PM levels during haze episodes.



✉ Correspondence address:
Global Atmosphere Watch Bukit Kototabang, Indonesian Agency for Meteorology Climatology and Geophysics, Agam, Indonesia
E-mail: aditya.prapanca@bmkg.go.id

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## INTRODUCTION

Forest and land fires (karhutla) are one of the dominant sources of atmospheric emissions in Indonesia, particularly during the dry season (Field et al., 2016; Huijnen et al., 2016; Stockwell et al., 2016). Indonesia has experienced recutpent haze episodes over the past decades, affecting both domestic and regional areas, such as the Southeast Asian haze events in 2010 and 2019 driven by extensive forest fires in Sumatra and Kalimantan (Yokelson et al., 2022). During the period of May July 2025, several regions in West Sumatra Province reported an expansion of burned areas exceeding 200 hectares, triggering haze events that significantly degraded regional and local air quality (Hendra, 2025). Smoke from these events transported large amounts of particulate pollutants, including fine particulate matter (PM2.5) and coarse particulate matter (PM10), which have substantial implications for air quality and public health.

Short-term exposure to PM2.5 has been shown to significantly increase the risk of mortality and acute respiratory disorders, highlighting the importance of understanding its temporal variability (Chen et al., 2021; Orellano et al., 2020) . Previous studies have demonstrated that meteorological variables play a critical role in influencing fluctuations in particulate matter (PM) concentrations across 1 Commented [AP1]: Sudah diperbaiki formatnya sesuai pedoman template jurnal. different geographical and seasonal contexts, primarily through atmospheric dispersion, accumulation, and transport processes. Research conducted by Wandayantolis et al., 2023 at the Bukit Kototabang Global Atmosphere Watch (GAW) station in West Sumatra revealed pronounced diurnal and seasonal variations in PM10 concentrations, with higher levels observed during periods of minimum rainfall compared to maximum rainfall, indicating the significant role of precipitation as an atmospheric cleansing mechanism through rain scavenging. The study further showed that although the direct cotpelations between PM10 and air temperature as well as relative humidity were relatively weak, atmospheric dynamics such as planetary boundary layer stability and wind speed played a crucial role in regulating particulate accumulation, particularly at intradiurnal scales. Similar findings were reported in Jambi City, where PM2.5 concentrations tended to increase at night and during the dry season, when atmospheric conditions are more stable and wind speeds are relatively low, and to decrease during the rainy season due to enhanced wet deposition and atmospheric ventilation (Benedy, 2025).

Globally, numerous studies have examined the influence of meteorological parameters on particulate matter distribution using Pearson and Spearman cotpelation approaches to evaluate relationships between atmospheric variables and pollutant concentrations (Harcourt et al., 2019; Hien et al., 2019; M. Islam et al., 2015; Lee, 2014; Qin & Lou, 2019; Singh et al., 2021). Statistical analyses in Seoul, South Korea, showed that most air pollutants, including PM2.5, PM10, $SO_2$, $O_3$, and CO, were intercotpelated, with $O_3$ exhibiting distinct relationship patterns (Lee, 2014). In Dhaka, Bangladesh, PM2.5 and PM10 concentrations were reported to be positively cotpelated due to limited atmospheric dilution associated with low wind speeds, while their positive relationships with NOx suggested a linkage between increased particulate concentrations and decreases in air temperature and relative humidity (M. Islam et al., 2015). In contrast, studies in Ho Chi Minh City, Vietnam, identified a negative relationship between PM2.5 and wind speed, emphasizing the role of atmospheric ventilation in reducing particulate concentrations (Hien et al., 2019). In Ratchaburi, Thailand, PM2.5 exhibited strong positive cotpelations with PM10, CO, and $NO_2$, along with weaker positive cotpelations with temperature and relative humidity, reflecting the complex interactions between meteorological factors and emission sources in controlling particulate concentrations (Kliengchuay et al., 2022).

Based on these considerations, this study aims to characterize the short-term variability of PM2.5 and PM10 concentrations during the forest and land fire episode in West Sumatra from May to July 2025. In addition, this study investigates the influence of meteorological parameters, including wind direction and speed, relative humidity, and atmospheric conditions, on the dynamics of particulate concentrations during haze events. Through this analysis, the study aims to identify the dominant meteorological factors governing daily and monthly fluctuations of PM2.5 and PM10. The findings are expected to provide a more comprehensive understanding of the mechanisms controlling particulate concentrations during smoke episodes and to serve as a scientific basis for air quality management and mitigation strategies in the future.

## MATERIALS AND METHOD

### Study Area

The study area is located in West Sumatra, Indonesia, specifically within regions affected by forest and land fires (karhutla), including Limapuluh Kota Regency, Solok Regency, Pesisir Selatan Regency, Payakumbuh City, and Pasaman Regency. This study utilizes daily PM2.5 and PM10 concentration data obtained from measurements conducted at the Bukit Kototabang Global Atmosphere Watch (GAW) station. The station is situated at an elevation of 864 m above sea level, with geographic coordinates of 0°12′07″ S and 100°19′05″ E. The monitoring site is located on a hilltop and is relatively remote from direct anthropogenic pollution sources, making it representative of regional background atmospheric conditions.

### Data

1. Particulate matter data consist of daily PM2.5 and PM10 concentrations for the period April August 2025, sourced from the Bukit Kototabang Global Atmosphere Watch station. April is defined as the pre-fire period, May–July as the fire (karhutla) period, and August as the post fire period.
2. Daily meteorological data, including rainfall, air temperature, and relative humidity, were obtained from the Automatic Agroclimate Weather Station (AAWS) at the Bukit Kototabang Global Atmosphere Watch station for the same period. Wind speed and wind direction data were derived from ECMWF reanalysis products covering April–August 2025.

### Research Methods

***Data Pre processing***

Prior to statistical analysis, all datasets underwent quality control procedures, including the identification of missing values and detection of outliers. Missing data were handled using linear interpolation when their proportion was below 10%. For datasets with higher proportions of missing values, the data were either analyzed separately or excluded from further analysis.
Outliers were identified using the Z-score method, expressed as:

$$Z : \frac{(xi - \bar{x})}{s} \quad (1)$$

where xi represents the observed value, $\bar{x}$ is the sample mean, and s is the standard deviation. Observations with absolute Z-score values greater than 3 were removed or further evaluated (Prasetyo et al., 2025).

***Identification of Haze Events***

Haze events were defined as periods when PM2.5 and PM10 concentrations exceeded the 90th percentile threshold, representing extreme pollution conditions (Zheng et al., 2023).

***Particulate Matter Time Series Analysis***

1. Absolute Analysis

This analysis was conducted to directly examine daily PM2.5 and PM10 concentrations and to visualize short-term temporal trends.

2. PM2.5 to PM10 Ratio
The PM2.5/PM10 ratio was used to infer particle composition using the following equation (Cazacu, 2025):

$$Ratio : \frac{\text{PM2.5}}{\text{PM10}} \quad (2)$$

Higher ratio values indicate a dominance of fine particles relative to coarse particles.

***Analysis of the Relationship between Meteorological Variables and PM Cotpelation Analysis***
The Spearman rank correlation method was applied to evaluate the relationship between particulate matter concentrations and meteorological parameters. This non-parametric approach was selected due to the non-normal distribution of the data. The correlation coefficient is defined as:

$$rs : \frac{1 - (6\,\Sigma \text{di}^2)}{[\text{n}(\text{n}^2 - 1)]} \quad (3)$$

where $di$ represents the difference between paired ranks and $n$ is the number of observations.

***Analysis Composite***
This analysis compares the mean meteorological conditions between high-PM (haze) days and low PM (non-haze) days. The Mann–Whitney U test was applied to assess whether meteorological conditions differed significantly between the two groups, calculated as follows (Bell et al., 2004):

$$U : n1n2 + \frac{\text{n1}(\text{n1} + 1)}{2} - R1 \quad (4)$$

where $n1$ and $n2$ are the sample sizes of the two groups, and $R1$ is the sum of ranks for the first group.

***Multivariate Regression Analysis***
Multivariate regression analysis was conducted to evaluate the simultaneous influence of meteorological variables on PM2.5 and PM10 concentrations, expressed as (Manevska et al., 2025):

$$PM2.5 = \beta 0 + \beta 1(WS) + \beta 2(Rain) + \beta 3(RH) + \beta 4(Temp) + \varepsilon \quad (5)$$

where $WS$ denotes wind speed, Rain represents rainfall, $RH$ is relative humidity, Temp is air temperature, and $\varepsilon$ is the etpor term. The regression coefficients ($\beta$) were standardized to facilitate comparison of the relative influence of each meteorological variable.

## RESULTS AND DISCUSSION

### Data Characteristics and Exploratory Data Analysis (EDA).

The EDA results presented in Table 1 indicate that the PM2.5 dataset contains nine missing days, accounting for 5.88% of the total observations. This proportion is considered low; therefore, the missing values were filled using linear interpolation in accordance with the data pre-processing procedure. In contrast, the PM10, rainfall (tp), mean air temperature (temp), and relative humidity (rh) datasets show no missing values (0%), reflecting the high reliability of the measurement instruments throughout the observation period.

Table 1. Exploratory Data Analysis (EDA) of Daily PM2.5, PM10, Rainfall (tp), Mean Air Temperature (temp), Relative Humidity (rh), Wind Speed at 10 m (ws10), and Wind Speed at 100 m (ws100) during April–August 2025 at the Bukit Kototabang GAW Station.

| Metrics | PM2.5 | PM10 | tp | temp | rh | ws10 | ws100 |
|---|---|---|---|---|---|---|---|
| Missing | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| Missing (%) | 5,88 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 6,6 | 10,43 | 3,72 | 21,52 | 90 | 0,63 | 1,21 |
| Minimum | 1,68 | 2.57 | 0 | 18,86 | 74,29 | 0,09 | 0,07 |
| Maximum | 27,53 | 30,17 | 43,5 | 23,63 | 100 | 1,46 | 2,48 |

Based on descriptive statistics for the pre-, during-, and post-fire periods in West Sumatra in 2025, the average daily PM2.5 concentration measured at the Bukit Kototabang GAW station was 6.6 $\mu g\ m^{-3}$, with a minimum of 1.68 $\mu g\ m^{-3}$ and a maximum of 27.53 $\mu g\ m^{-3}$. Meanwhile, PM10 exhibited a higher average daily concentration of 10.43 $\mu g\ m^{-3}$, ranging from 2.57 $\mu g\ m^{-3}$ to 30.17 $\mu g\ m^{-3}$. This difference reflects particle size characteristics, as PM10 generally contributes a larger mass concentration than PM2.5.

**Monthly Variations of PM2.5 and PM10 Concentrations and the PM2.5/PM10 Ratio**

Figure 1 illustrates the monthly variations of PM2.5 and PM10 concentrations and the PM2.5/PM10 ratio during the pre-fire (April), fire (May–July), and post-fire (August) periods of 2025 at the GAW Bukit Kototabang station. During the pre-fire period (April), PM2.5 and PM10 concentrations remained relatively low, as indicated by a natpow data distribution. Entering the fire period (May–July), both PM2.5 and PM10 concentrations increased markedly, with peak values generally occutping in June. This increase was accompanied by substantially higher day-to-day variability compared to the pre-fire period, highlighting the episodic nature of air pollution associated with forest and land fires across several districts in West Sumatra.

The increase in PM concentrations during the fire period was also characterized by dominant PM2.5/PM10 ratios exceeding 0.6. During the pre-fire phase (April), the ratio was already relatively high (0.69), indicating fine-particle dominance under background conditions. Throughout the fire period (May–July), the ratio remained elevated despite temporal fluctuations (May: 0.66; June: 0.62; July: 0.65). This pattern suggests an enhanced contribution of PM2.5, primarily associated with biomass burning emissions. These findings are consistent with previous studies indicating that PM2.5/PM10 ratios greater than 0.5 reflect dominance of fine particles, which are closely linked to primary emissions from anthropogenic activities (Jaqueline et al., 2024; Sirithian & Thanatrakolsri, 2022), as well as secondary particle formation involving nitrates, sulfates, ammonium, and organic compounds (Yue et al., 2010)

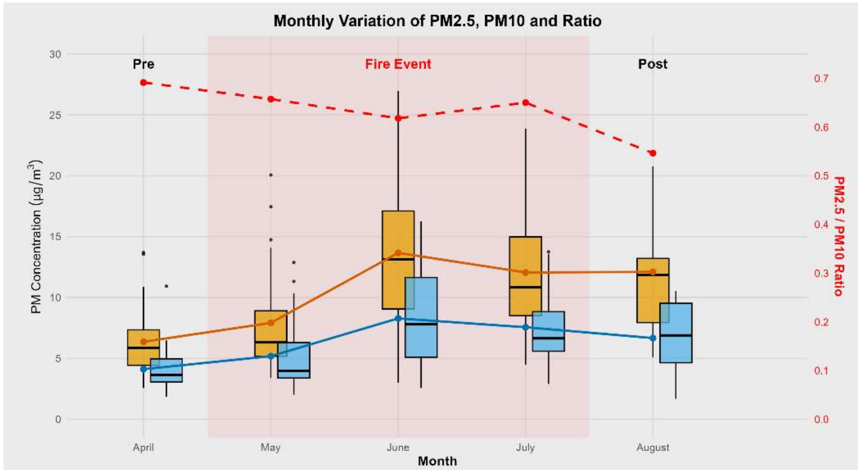
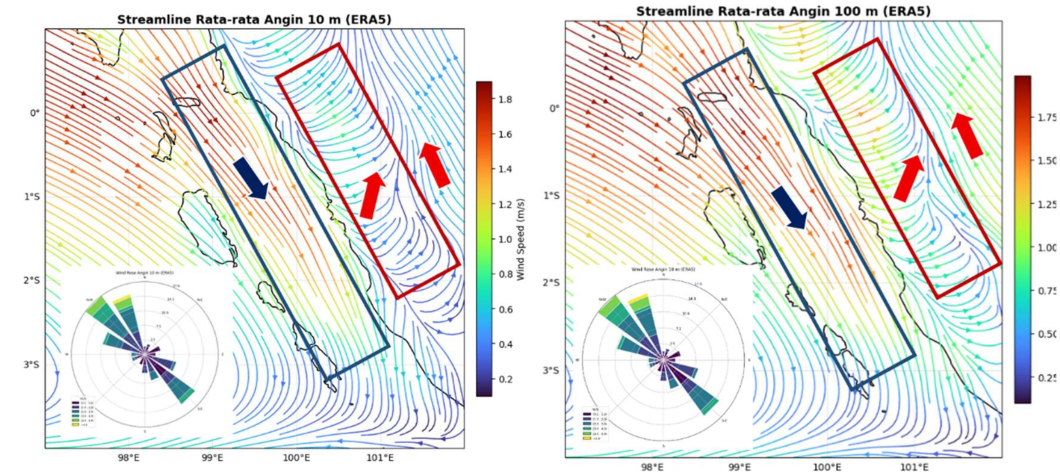



Figure 1. Boxplots of monthly mean PM concentrations and PM2.5/PM10 ratios during the pre-fire (April), fire (May–July), and post-fire (August) periods of the 2025 forest and land fire event in West Sumatra at the Bukit Kototabang GAW Station.

Reports from national media and official disaster management agencies indicate that forest and land fires in West Sumatra during May–July 2025 were predominantly triggered by human activities. Suspected ignition sources include land clearing through open burning, burning of agricultural residues, and human negligence, such as the presence of ignition sources in dry land areas (ANTARA, 2025; Hendra, 2025; Media Indonesia, 2025; Mongabay Indonesia, 2025). These activities were further exacerbated by dry-season conditions characterized by high temperatures and low rainfall, allowing fires to spread rapidly across forested and sutpounding areas. During the post-fire period (August), the PM2.5/PM10 ratio declined but remained above 0.5, indicating that fine particles continued to dominate particulate composition.

**Analysis of Particulate Transport Pathways**

Particulate transport was examined using wind field conditions at 10 m and 100 m heights. Figure 2. (a) and (b) reveals wind shear and near-surface flow convergence over the coastal and mountainous regions. In this study, these features are interpreted as evidence of localized topographic control on low-level airflow, consistent with the findings of Ganbat and Seo, (2014). Over land, winds predominantly originated from the southeast toward the north, whereas over the ocean, winds mainly flowed from the northwest toward the southeast.




**(a)** **(b)**

Figure 1. (a) Wind streamlines and wind rose at 10 m height; (b) wind streamlines and wind rose at 100 m height.

Wind speeds at 10 m were stronger over the ocean (1–2 m $s^{-1}$) than over land (<1 m $s^{-1}$). The relatively weak wind speeds over land are attributed to surface friction, complex topography, mountainous tetpain, and vegetation cover (Finnigan et al., 2020; Maharani et al., 2009). These conditions favor longer atmospheric residence times of particulate matter, promoting accumulation and enhanced dry deposition processes (Farmer et al., 2023).

During the fire period, particulate dispersion was mainly concentrated over inland areas and advected toward urban regions located downwind. This pattern indicates that horizontal advection acted as the primary mechanism governing particulate transport (Kesti et al., 2024). However, weak wind speeds over land limited turbulent diffusion, causing particulates to accumulate within the lower atmospheric layers.

A similar pattern was observed at the 100 m wind level (Figure 2b), although wind speeds increased over both land and ocean. This suggests that particulate transport at 100 m occutped more efficiently than at 10 m. These findings are consistent with previous studies reporting an increase in wind speed with height due to reduced surface friction (Andrea et al., 2011; Park et al., 2025).

**Spearman Rank Cotpelation Analysis**

The relationships between PM2.5, PM10, and meteorological parameters were examined using Spearman rank cotpelation, which is suitable for non-parametric and non-normally distributed data. PM2.5 and PM10 exhibited a very strong positive cotpelation ($r = 0.93$), indicating that both particulate fractions shared similar emission sources and transport mechanisms during the study period.

PM2.5 and PM10 showed weak positive cotpelations with air temperature ($r = 0.16$ and $r = 0.12$, respectively; Figure 3), suggesting that temperature was not a dominant factor controlling surface-level particulate accumulation. This result is consistent with the findings of Sari et al. (2025), which indicate that higher daytime temperatures enhance vertical mixing in the atmosphere, thereby reducing PM concentrations near the surface.


Figure 2. Spearman rank cotpelation.

In contrast, PM2.5 and PM10 exhibited negative cotpelations with rainfall (tp), relative humidity (RH), and wind speed at both 10 m (WS10) and 100 m (WS100). These results are consistent with (Teani et al., 2021), who found that meteorological parameters generally exhibit weak cotpelations with particulate concentration variability. However, other studies have reported positive cotpelations between relative humidity and particulate concentrations (Li et al., 2017; Maulydia, 2024), highlighting the complexity of PM–meteorology interactions.

The strongest negative cotpelations were observed between PM concentrations and rainfall ($r = -0.36$) as well as wind speed at 100 m ($r = -0.31$). These findings suggest that PM2.5 and PM10 variability during the study period was primarily driven by common emission sources and transport processes rather than by meteorological parameters alone. Nevertheless, the negative cotpelations indicate that meteorological conditions still modulate particulate accumulation and dispersion, albeit with relatively weak influence.

**Composite Analysis**

Composite analysis was performed by comparing meteorological conditions between episodic high-PM days and non-episodic days. High-PM episodes were defined as days when PM2.5 and PM10 concentrations exceeded the 75th percentile, representing particulate accumulation conditions. For both PM2.5 and PM10, air temperature during episodic periods was higher than during non-episodic periods (Tables 2 and 3). This difference was statistically significant for PM2.5, indicating that relatively higher temperatures may indirectly contribute to increased particulate concentrations, although the effect is not direct (Maulydia, 2024). For PM10, the temperature difference was not statistically significant.

Table 1. Composite Meteorological Conditions during High and Non-Episodic PM2.5 Periods

| Parameter | Mean PM (High Episode) | Mean PM (Non-Episode) | p_value | Significant ($p < 0.05$) |
|---|---|---|---|---|
| Temp (t) | 21.98 | 21.51 | 0.043 | TRUE |
| Rainfall (tp) | 0.59 | 4.34 | 0.113 | FALSE |
| Relative Humidity (rh) | 88.04 | 89.75 | 0.197 | FALSE |

| | | | | |
|---|---|---|---|---|
| Wind Speed 10 m (WS10) | 0.57 | 0.72 | 0.02 | TRUE |
| Wind Speed 100 m (WS100) | 1 | 1.41 | 0.042 | TRUE |

Rainfall (tp) and relative humidity (RH) showed no statistically significant differences between episodic and non-episodic periods, although mean values were lower during episodic days. This suggests that reduced rainfall may limit wet deposition efficiency, allowing particulate matter to accumulate in the atmosphere. This finding aligns with previous studies indicating that rainfall negatively affects PM2.5 and PM10 concentrations through washout processes, with a stronger effect on PM10 due to its larger particle size (Muhammad Lutfi Aditya et al., 2023). Additionally, relative humidity may suppress particle deposition and enhance particulate accumulation near the surface (Souza et al., 2025).

Table 2. Composite Meteorological Conditions during High and Non-Episodic PM10 Periods

| Parameter | Mean PM (High Episode) | Mean PM (Non-Episode) | p_value | Significant ($p < 0.05$) |
|---|---|---|---|---|
| Temp (t) | 21.88 | 21.54 | 0.170 | FALSE |
| Rainfall (tp) | 0.59 | 4.34 | 0.113 | FALSE |
| Relative Humidity (rh) | 88.01 | 89.76 | 0.194 | FALSE |
| Wind Speed 10 m (WS10) | 0.59 | 0.72 | 0.071 | FALSE |
| Wind Speed 100 m (WS100) | 1.08 | 1.41 | 0.01 | TRUE |

For wind speed at 10 m (WS10), mean values during episodic periods were lower than during non-episodic periods, with the difference being statistically significant for PM2.5 but not for PM10. This indicates that near-surface wind variability contributes to distinguishing episodic from non-episodic conditions. In contrast, wind speed at 100 m (WS100) exhibited a statistically significant difference, with lower mean values during episodic periods. This finding suggests that weakened winds aloft reduce regional-scale transport and dispersion efficiency, thereby favoring particulate accumulation near the surface (Kesti et al., 2024). Overall, the composite analysis demonstrates that meteorological conditions characterized by higher temperatures, lower rainfall and relative humidity, and weakened upper-level winds play an important role in enhancing PM2.5 and PM10 concentrations (Souza et al., 2025; Zhang et al., 2018).

**Multivariate Regression Analysis of PM2.5 and PM10**

The regression results indicate that the PM2.5 model yielded an $R^2$ value of 0.252 and an adjusted $R^2$ of 0.208, suggesting that approximately 20–25% of the variability in PM2.5 concentrations can be explained by the meteorological parameters included in the model. The F-statistic of 5.791 with a p-value < 0.001 indicates that the overall model is statistically significant (Table 4).

Table 3. Model Statistics for PM2.5 and PM10

| Statistic Model | PM2.5 | PM10 |
|---|---|---|

| | | |
|---|---|---|
| Frequency of Obs (n) | 92 | 92 |
| $R^2$ | 0.252 | 0.241 |
| Adjusted $R^2$ | 0.208 | 0.197 |
| F-statistic | 5.791 | 5.474 |
| Prob (F-statistic) | <0.001* | <0.001* |
| Durbin–Watson | 0.876 | 0.705 |

As shown in Table 5, relative humidity (RH) and wind speed at both 10 m (WS10) and 100 m (WS100) exerted significant effects on PM2.5 concentrations. Relative humidity exhibited a significant negative standardized coefficient (β = −0.894; p < 0.022), indicating that higher RH is associated with lower PM2.5 concentrations. In contrast, WS10 showed a significant positive coefficient (β = 2.985; p = 0.002), suggesting that increased near-surface wind speed was associated with higher PM2.5 levels. Meanwhile, WS100 displayed a significant negative effect (β = −3.835; p < 0.001), reflecting the role of upper-level winds in enhancing particulate dispersion and regional transport (Patpa et al., 2024).

Temperature (t) and rainfall (tp) did not exhibit statistically significant effects (p > 0.05), indicating that these parameters were not primary controlling factors for PM2.5 variability during the observation period. Based on the standardized beta coefficients, relative humidity exerted the strongest influence on PM2.5 ($\beta_{std}$ = −3.52), followed by wind speed at 100 m (WS100; $\beta_{std}$ = −0.88) and wind speed at 10 m (WS10; $\beta_{std}$ = 0.38). These results emphasize that atmospheric dynamics and moisture conditions play a more substantial role in regulating PM2.5 concentrations than air temperature alone (Hendon, 2003).

Table 4. Results of Multivariate Linear Regression between Meteorological Parameters and PM2.5 Concentrations *(Notes: β = unstandardized regression coefficient; β$std$ = standardized beta coefficient; SE = standard etpor; significant at the 95% confidence level (p < 0.05).)

| Independent Variable | PM2.5 (β) | SE | P-Value | βstd |
|---|---|---|---|---|
| Constanta | 6.959 | 0.308 | <0.001* | – |
| Temp (t) | −0.183 | 0.396 | 0.645 | −0.24 |
| Rainfall (tp) | −0.558 | 0.317 | 0.082 | −4.93 |
| Relative Humidity (rh) | −0.894 | 0.382 | 0.022 | −3.52 |
| Wind Speed 10 m (WS10) | 2.985 | 0.950 | 0.002* | 0.38 |
| Wind Speed 100 m (WS100) | −3.835 | 0.969 | <0.001* | −0.88 |

Table 6 presents the results of the multivariate linear regression analysis between meteorological parameters and PM10 concentrations. The regression model yielded an $R^2$ value of 0.241 and an adjusted $R^2$ of 0.197, indicating that approximately 19-24% of the variability in PM10 concentrations can be explained by the meteorological parameters included in the model. In addition, the F-statistic of 5.474 with a p-value < 0.001 confirms that the model is statistically significant.

As shown in Table 6, relative humidity (rh), rainfall (tp), wind speed at 10 m (WS10), and wind speed at 100 m (WS100) significantly influence PM10 concentrations, whereas temperature (t) does not show a statistically significant effect (p > 0.05). Relative humidity exhibits a significant negative effect (β = −2.31; p < 0.001), highlighting the important role of atmospheric moisture in reducing PM10 concentrations through enhanced deposition and settling processes. Rainfall also shows a significant negative effect (β = −1.175; p = 0.029), suggesting that wet scavenging contributes to the removal of particulate matter from the atmosphere. In contrast, WS10 shows a significant positive effect (β = 4.177; p = 0.010), whereas WS100 exerts a significant negative effect (β = −5.372; p = 0.001), further emphasizing the contrasting roles of near-surface and upper-level winds in regulating particulate distribution. Based on the standardized beta coefficients reported in Table 6, relative humidity is the most dominant parameter affecting PM10 (βstd = −2.13), followed by rainfall (βstd = −2.98), WS100 (βstd = −0.53), and WS10 (βstd = 0.23).

Table 5. Results of Multivariate Linear Regression between Meteorological Parameters and PM10 Concentrations *(Notes: β = unstandardized regression coefficient; $\beta std$ = standardized beta coefficient; SE = standard e*tp*or; significant at the 95% confidence level (p < 0.05).)

| Independent Variable | PM10(β) | SE | P-Value | βstd |
|---|---|---|---|---|
| Constanta | 11.152 | 0.513 | <0.001* | – |
| Temp (t) | −1 | 0.659 | 0.132 | −0.14 |
| Rainfall (tp) | −1.175 | 0.528 | 0.029 | −2.98 |
| Relative Humidity (rh) | −2.31 | 0.637 | <0.001* | −2.13 |
| Wind Speed 10 m (WS10) | 4.177 | 1.582 | 0.010* | 0.23 |
| Wind Speed 100 m (WS100) | −5.372 | 1.613 | 0.001* | −0.53 |

Overall, the multivariate regression results indicate that relative humidity is one of the most influential meteorological factors controlling variations in PM2.5 and PM10 concentrations. In addition, the contrasting signs of the regression coefficients for WS10 and WS100 suggest that near-surface winds are associated with increased particulate concentrations, potentially due to resuspension processes or localized transport, whereas upper-level winds enhance atmospheric dispersion and regional transport, thereby reducing particulate concentrations near the surface (Islam et al., 2023). The relatively moderate $R^2$ values further indicate that, in addition to meteorological influences, emission sources and forest and land fire activities likely play a substantial role in determining PM2.5 and PM10 variability during the observation period (Xing, 2022).

## CONCLUSION

1. Forest and land fire events during May–July 2025 in West Sumatra led to a significant increase in PM2.5 and PM10 concentrations. The dominance of fine particles, indicated by PM2.5/PM10 ratios exceeding 0.6, reflects the strong contribution of biomass burning emissions during haze episodes, characterized by pronounced episodic pollution patterns.
2. PM2.5 and PM10 concentrations exhibited a very strong positive cotpelation, indicating common emission sources and similar particulate transport mechanisms within the study area. Overall, meteorological parameters showed relatively weak direct relationships with particulate concentrations; however, they still played an important role in modulating atmospheric accumulation and dispersion processes.
3. Composite and multivariate regression analyses reveal that relative humidity and wind speed are the most influential meteorological factors affecting variations in PM2.5 and PM10. Weakened wind conditions, particularly in the upper atmospheric layers, combined with lower relative humidity, favor particulate accumulation near the surface, while emissions from forest and land fires remain the primary drivers of elevated PM concentrations during haze episodes.

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