POLICY DIALOGUES

Impact of Meteorological Factors and Extreme Weather Events on $PM_{2.5}$ Pollution in Viet Nam

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KEY FACTS

•Air pollution from fine particulate matter ($PM_{2.5}$) has become a growing threat to health and the environment across Vietnam.

•This study provides key insights into how meteorological factors and extreme weather events influence $PM_{2.5}$ levels across six socio-economic regions from 2012 to 2022.

•Our findings reveal that surface pressure and temperature are the strongest meteorological drivers of $PM_{2.5}$ variability across Vietnam, with regional differences in how rainfall, humidity, and wind speed affect pollution levels, and that extreme weather events can both significantly increase and decrease $PM_{2.5}$ concentrations.

•Understanding climate influences on PM2.5 can enhance pollution forecasting, guide targeted actions, and integrate air quality into climate adaptation and disaster preparedness to protect health and strengthen resilience.

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Key words *PM*2.5, Meteorological factors, Extreme weather events, Vietnam

Geography Viet Nam

Themes: Environment, Climate

Find out more about this project: https://www.afd.fr/en/gemmes-vietnam-analysis-socio-economic-impacts-climate-change-energy-transition-and-adaptation-strategies

CONTEXT & MOTIVATION

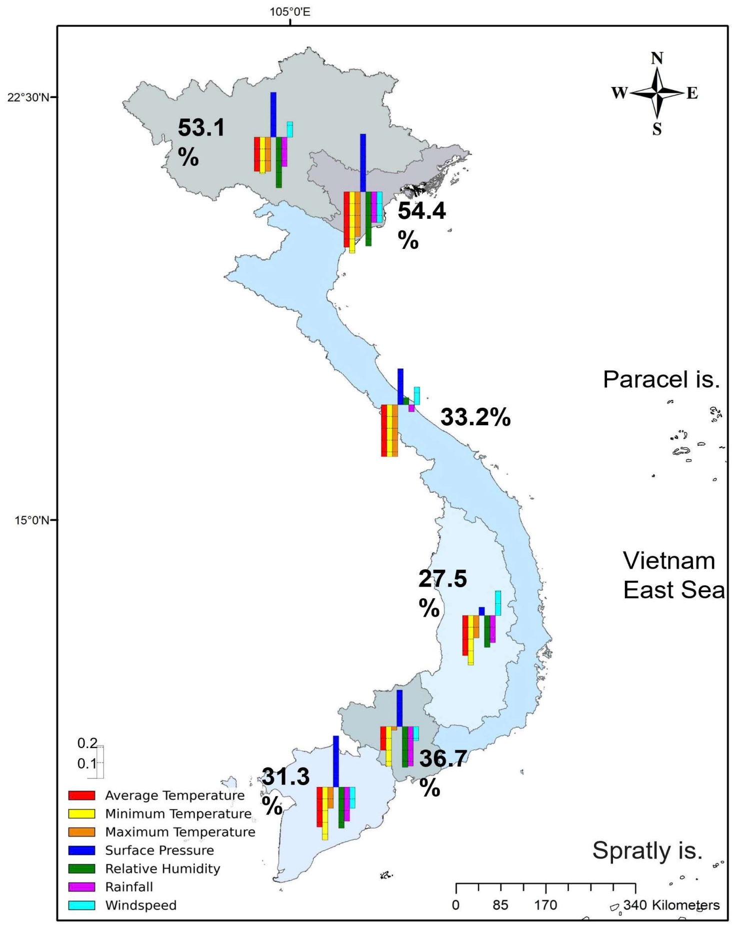
Air pollution is a major global challenge, with $PM_{2.5}$ being among the most harmful pollutants. Its levels are influenced by both emissions and meteorological factors, which vary by geography and climate. Unlike previous studies focused on local ground data and therefore limited in regional-level data and analysis, this study uses modeled data from multiple sources to examine these relationships at a national scale, offering a broader perspective previously unexplored.

This study[1] offers a comprehensive overview of how various meteorological factors interact with $PM_{2.5}$ across the country, supporting more informed air quality management, climate adaptation, and disaster preparedness. Additionally, the findings provide valuable datasets for evaluating Vietnam's progress toward its Net-Zero emissions target by 2050.

METHODOLOGY

We first assess the cumulative effects of meteorological variables (temperatures, humidity, rainfall, surface pressure, and wind speed) to identify the most relevant lag days for analysis. We then explore general and spatial correlations at the district levels using Pearson's r (linear) and Spearman's R (non-linear). To quantify the combined influence of climate factors on $PM_{2.5}$ fluctuations, we conduct multivariate analyses using Linear Regression (LR) and Generalized Additive Models (GAM).

Fig.1 Pearson correlations between meteorological factors and $PM_{2.5}$ and the proportion of variance in the $PM_{2.5}$ concentration explained by combined meteorological variables using GAM models over six socio-economic regions

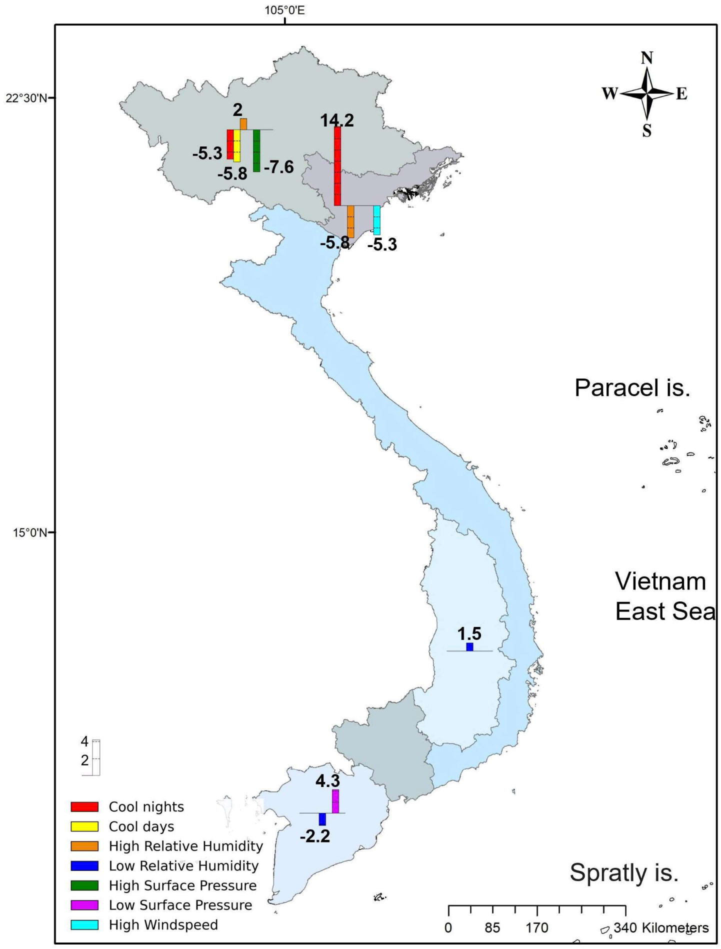


Then, we identify extreme weather events, such as unusually cool or warm nights and days, extreme humidity, pressure, wind speed, or $PM_{2.5}$ levels, based on the 5th and 95th percentiles of historical data. We examine their overlap with $PM_{2.5}$ extremes and estimate the impact of event durations on pollution using a Two-Way Fixed Effects (TWFE) model.

Finally, we illustrate our findings through two case studies: the 2016 drought in southern Vietnam and Typhoon Talas in 2017, analyzing their impact on air quality using a Difference-in-Differences (DID) approach.

KEY FINDINGS

Fig.2 Some long-lasting extreme weather events can significantly increase or decrease $PM_{2.5}$ concentration ($\mu g/m^3$) on six socio-economic regions



Meteorological drivers and regional variations. Rainfall and wind speed tend to have immediate effects on $PM_{2.5}$ levels, while temperature and humidity influence concentrations over longer periods in northern regions. In southern regions, all factors show more immediate impacts. Surface pressure has especially shown strong variation by time lags only in the delta regions but others.

Surface pressure stands out as the strongest positive driver of $PM_{2.5}$ (except in Central Highlands), as higher pressure suppresses air movement and traps pollutants. Temperature is the second most influential factor, with cooler temperatures (especially daily minimums) linked to higher $PM_{2.5}$, particularly in the Red River Delta. Humidity and rainfall usually reduce $PM_{2.5}$, except in North Central Coast, where humidity shows a positive correlation. Wind speed effects vary by region, low wind speed increases $PM_{2.5}$ in some northern areas while elsewhere high wind speed brings and increases air pollution. Combined models explain up to 54% of $PM_{2.5}$ variability in northern regions but less in southern areas, indicating additional pollution sources beyond meteorological factors.

Impacts of extreme weather events. Cool days, heavy rainfall, and high winds are associated with lower $PM_{2.5}$ levels, particularly in northern regions, where these weather events coincide with very low $PM_{2.5}$ in more than 15% of the time. Conversely, cool nights, low humidity, and low winds tend to coincide with higher pollution levels. Warm weather and low-pressure events show limited overlap with $PM_{2.5}$ extremes. Quantitatively, cool nights, low pressure, low wind events significantly increase $PM_{2.5}$, while cool days, rainfall, high humidity, high pressure reduce it. For example, prolonged cool nights in the Red River Delta can spike $PM_{2.5}$ by 14.2 $\mu g/m^3$, whereas in the Northern Mountain region, similar conditions reduce $PM_{2.5}$ by up to 7 $\mu g/m^3$. These findings highlight the importance of both the type and duration of extreme events in shaping air quality responses.

Drought and typhoon case studies. Two major events show how extreme weather can impact air quality. The 2016 drought in Southern Vietnam raised $PM_{2.5}$ by 6.45 µg/m³ in the Mekong Delta, reflecting how dry spells intensify pollution in vulnerable lowland areas. In contrast, Typhoon Talas (2017) reduced $PM_{2.5}$ by 2.05 µg/m³ in Central Vietnam, likely due to strong winds and rainfall dispersing pollutants. These cases highlight how different extreme events can worsen or improve locally air quality depending on their nature and location.

Limitations. The findings are subject to methodological and data-related constraints. The quality of meteorological and $PM_{2.5}$ data may affect accuracy. The TWFE model assumes stable district- and time-specific effects, which may simplify real-world dynamics. The DID method depends on parallel trends between treatment and control groups, which may not always hold. Also, defining extreme events, selecting data for TWFE and DID models, and the limited number of case studies may limit the generalizability of the results.

RECOMMENDATIONS

- Integrated climate-air quality modeling: Current and lag-day values of meteorological variables, such as surface pressure, temperature, rainfall, relative humidity, wind speed and extreme event patterns, should be integrated into regional air quality models to enhance their accuracy. The models should be used to forecast periods of severe pollution, enabling more proactive and flexible adaptation planning.
- Climate change adaptation and mitigation: The strong link between meteorological factors and air pollution in northern regions suggests that future climate change may worsen air quality, with serious implications for human health and the environment. Therefore, air pollution should be integrated into climate change adaptation and mitigation strategies. This can include incorporating air quality indices into urban planning and public health alert systems, implementing early warning systems about hazardous pollution levels, transitioning to renewable energy, promoting sustainable transport, improving waste and agricultural practices, expanding urban green spaces, and strengthening healthcare infrastructure.
- Disaster preparedness and resilience: Extreme weather events such as cool nights, low humidity, and low wind speed often coincide with high $PM_{2.5}$ concentration. Prolonged extreme events, like cool nights in the Red River Delta, low surface pressure in the Mekong River Delta, and droughts, can significantly increase $PM_{2.5}$ levels. Strengthening disaster preparedness and resilience is essential to mitigate these combined impacts.

[1] Nguyen et al. (2025) Impact of Meteorological Factors and Extreme Weather Events on PM2.5 Pollution in Vietnam, *AFD Research Paper* 364