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A study on $PM_{2.5}$ concentration in Bangkok, Thailand: A case study of Bang Na Station

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ABSTRACT

In contemporary times, air pollution has emerged as a pressing concern in major metropolises worldwide. Particulate matter, particularly $PM_{2.5}$, has been identified as a key contributor to elevated pollution levels. While previous studies in Thailand have primarily focused on $PM_{2.5}$ in agricultural, forestry, and industrial regions, they often examine its relationship with precursor gases (e.g., SO_2, NO_x, VOCs, and NH_3) and hotspots. However, research pertaining to the capital city, Bangkok, remains limited due to its complex source composition and unnatural urban structure, leading to unique airborne conditions. This study seeks to explore the interplay between $PM_{2.5}$, precursor gases, and meteorological factors in Bangkok. To assess the influence of precursor gases and meteorological variables on $PM_{2.5}$ concentrations, correlation analysis and regression techniques were applied to monitoring data obtained from relevant government agencies. Notably, $PM_{2.5}$ exhibited strong correlations with precursor gases, especially NO_2 (correlation coefficient, R, ranging from 0.11 to 0.87), while SO_2 showed more variable correlations (R ranging from -0.45 to 0.85). Furthermore, meteorological factors exhibited significant but slightly weaker correlations with $PM_{2.5}$ compared to SO_2 and NO_2. This suggests that NO_2 plays a dominant role in driving the secondary formation of $PM_{2.5}$ in the Bang Na area. Regression analysis confirmed the strong association of NO_2, SO_2, and relative humidity with $PM_{2.5}$, while other meteorological parameters displayed less significance, even the planetary boundary layer. Contrary to previous studies that primarily rely on real-time monitoring for short durations and emphasize potential pollution sources, our research underscores the pivotal role of precursor gases, particularly under high relative humidity conditions. To elucidate the secondary formation of $PM_{2.5}$ from precursor gases within urban settings, future studies should encompass longer-term real-time monitoring of both precursor gases and meteorological variables, especially in urban areas.

1. Introduction

$PM_{2.5}$ is a harmful atmospheric component. If its concentration is height it affects the environment and human health. Particulate matter in the air can affect human health, particularly in high concentrations (Xing et al., 2016). PM_{10} or particulate matter with a diameter of 10 microns or less, can pass into and remain in the lung but $PM_{2.5}$ can pass through the lung barrier and enter the blood system (Byrd et al., 2010). Prolonged exposure can cause poor cardiovascular development, respiratory diseases, and lung cancer (WHO, 2020). The WHO's air quality guideline defines that the annual mean should not exceed 10 µg/m3, and the 24-hour mean should not exceed 25 µg/m^3. However, $PM_{2.5}$ concentration does not vary on only emission from source but also on meteorological parameters such as temperature, wind speed, wind direction, relative humidity, and planetary boundary layer height (Fahimeh and Azadeh, 2012). According to the Air Quality Index (AQI) of the Pollution Control Department (PCD, 2020), Ministry of Natural

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Resource and Environment of Thailand, $PM_{2.5}$ is a crisis issue in Bangkok these days because its AQI is in the range of 100-200 (orange color, meaning that it starts to affect human health) or 51-90 µg/m3 over 24 hours. Some days, the 24 hours of $PM_{2.5}$ concentration is above 91 µg/m^3 or more than 200 AQI, which undoubtedly impacts human health (WHO, 2020; Sooktawee et al., 2023).

$PM_{2.5}$ encompasses both primary $PM_{2.5}$ and secondary $PM_{2.5}$. Primary $PM_{2.5}$ primarily consists of primary organic matter, elemental carbon (EC), dust, coal smoke, and sea salt, which are directly discharged into the atmosphere by both anthropogenic and natural origins. Primary $PM_{2.5}$ is classified as a pollutant that is emitted directly from its source. Conversely, secondary $PM_{2.5}$ is a byproduct of chemical reactions initiated by precursor gases, namely sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and ammonia (NH_3). Secondary $PM_{2.5}$ is considered a pollutant that forms as a result of these precursor gases undergoing complex atmospheric transformations. This distinction between primary and secondary $PM_{2.5}$ is critical in understanding the diverse origins and formation mechanisms of particulate matter, contributing to our comprehension of air quality dynamics (Mathias and Wayland, 2019). The secondary $PM_{2.5}$ is mainly composed of nitrates, sulfates, ammonium salts, and secondary organics formed by chemical processes that involve gaseous precursors (i.e., SO_2, NO_x, and VOCs). The result of Teani et al. (2022) showed the $PM_{2.5}$ concentration with NO_x as a precursor significantly positively correlated in 2019 (r = 0.68) and 2020 (r = 0.63) while meteorological factors have a small correlation value to fluctuation in $PM_{2.5}$ and NO_x concentration except for air temperature (r = 0.3). According to Hodan and Barnard (2004), the NO_x contributed to the $PM_{2.5}$ formation differs greatly depending on atmospheric conditions, including temperature and humidity. Furthermore, Wang-Li (2015) suggested that most inorganic $PM_{2.5}$ in the atmosphere is the secondary which is formed through an acid or base neutralization process involving NO_x and NH_3 as precursors. Recently, a study revealed that the $PM_{2.5}$ in the eastern U.S. comprised of organic carbon, ammonium sulfate, and ammonium nitrate and directly emitted the species including oxidized metal, and under certain atmospheric conditions, NO_x emissions can be transformed to $PM_{2.5}$ nitrate ion similarly to SO_2 can be also converted to $PM_{2.5}$ sulfate ion (Baker and Foley, 2011).

A study on the influence of meteorological factors on $PM_{2.5}$ in Bangkok, Thailand: Case Study of Bang Na Station aimed to investigate the meteorological parameters and $PM_{2.5}$ relationships. If its concentration does not increase from the source (including primary and secondary sources), the meteorological parameters are the major factor in increasing concentration. This study's result can help provide or consider future mitigations or policies in air pollution management.

2. Method

This study uses statistical methods such as correction coefficient and regression analysis to find the relationship of pollutants (Bewick et al., 2003) ($PM_{2.5}$ and Precursor gases (SO_2 and NO_2)), $PM_{2.5}$ and the meteorological parameters at Bang Na (air pollution monitoring station of PCD). The study period was the months of November and December of year 2016, 2017, and 2018 which is the winter season and caused the air pollution crisis. Moreover, this period can avoid uncontrollable factors such as rain.

3. Results and discussion

From correlation coefficient analysis to finding the relationship between hourly $PM_{2.5}$ concentration and precursor gases (NO_2 and SO_2) and meteorological parameters (wind speed, wind direction, temperature, relative humidity, and planetary boundary layer height, the correlation coefficient value was calculated in Table1 but they are not significant when using regression method (R^2).

3.1. Relationship between NO_2, SO_2, and $PM_{2.5}$

The results showed a correlation coefficient (r) between 0.101 to 0.867. Due to the NO_2, a precursor gas that can convert to $PM_{2.5}$ (NO_2 is a substrate information of NH NO that is a major component of $PM_{2.5}$), the correlation should be strongly negative because when $PM_{2.5}$ increases, the NO_2 should decrease to produce the $PM_{2.5}$. Therefore, the positive correlation means the increase in $PM_{2.5}$ did not come from NO_2 formation (Fig. 1).

From the correlation coefficient analysis to find the relationship between hourly $PM_{2.5}$ concentration, precursor gases (NO_2 and SO_2), and meteorological parameters (wind speed, wind direction, temperature, relative humidity, and planetary boundary layer height, the correlation coefficient value was calculated as Table 1 but they are not significant when using regression method(R^2).

3.2. Wind speed and $PM_{2.5}$ relationship

A correlation between wind speed and $PM_{2.5}$ was found between -0.777 to 0.406 and showed a negative value 30 days from 38 selection days, having a value between -0.777 to -0.003, as shown in Table 1. Moreover, strong negative correlation values were found on 15 November and 12, 13 December 2016, and 11 December 2017. The relationship means that $PM_{2.5}$ increased at low wind speeds. The results are shown in Fig. 2.

3.3. Wind direction and $PM_{2.5}$ relationship

The value of the correlation coefficients(r) was between -0.543 to 0.690; they showed a strong positive correlation on 23 December 2017 (r = 0.69), meaning that the $PM_{2.5}$ concentration was mainly influenced by the northwest wind on that day.

3.4. Temperature and $PM_{2.5}$ relationship

The correlation coefficient of temperature and $PM_{2.5}$ were between -0.883 to 0.612. The r values had a negative 33 days from the 38 selection days. There was a strong negative correlation, between -0.883 and -0.697, on 5 November, 12,13 December 2016, 11,22 December 2017, and 18, and 20 December 2018. The strong negative correlation was due to the decreasing transformation in the nitrate and volatile organic component in the particle phase to the gas phase. In the winter, the nitrate concentration is enormous (Pan et al., 2019). Fig. 3 shows the trend of $PM_{2.5}$ and temperature.

3.5. Relative humidity and $PM_{2.5}$ relationship

The relative humidity (R.H.) positively related to $PM_{2.5}$ on most selected dates (34 days from 38 days). However, the r values were between -0.335 to 0.878. In addition, there were 13 days with a strong positive relationship (the value of r = 0.724 to 0.878) on the 5, 6 November and 12, 13, 19 December 2016, and 20, 26, 27 December 2018. The strong positive relationship means that R.H. affects the water content of nitrate particulate matter (Pan et al., 2019). Fig. 4 shows the trends of $PM_{2.5}$, R.H, and NO_2 are similar.

3.6. Planetary boundary layer height (PBLH) and $PM_{2.5}$ relationship

The correlation values (r) were between -0.514 to 0.867 and showed a medium negative relationship on 22 December 2018. The different dates consisted of a weak negative and a strong positive relationship, as shown in Fig. 5. $PM_{2.5}$ usually increased when the PBLH decreased. Still, most cases in this study showed a positive correlation, meaning $PM_{2.5}$ was influenced by the other factor, except the day with a negative correlation.

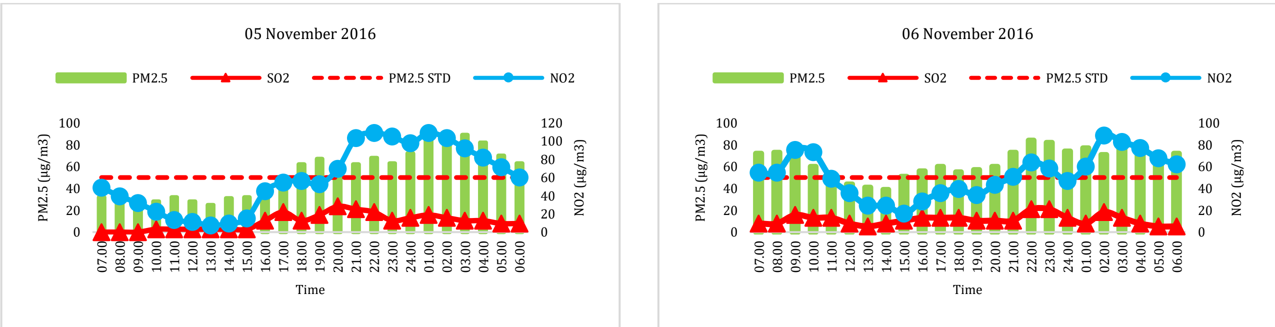

Fig. 1: Relationship between NO_2, SO_2 and $PM_{2.5}$

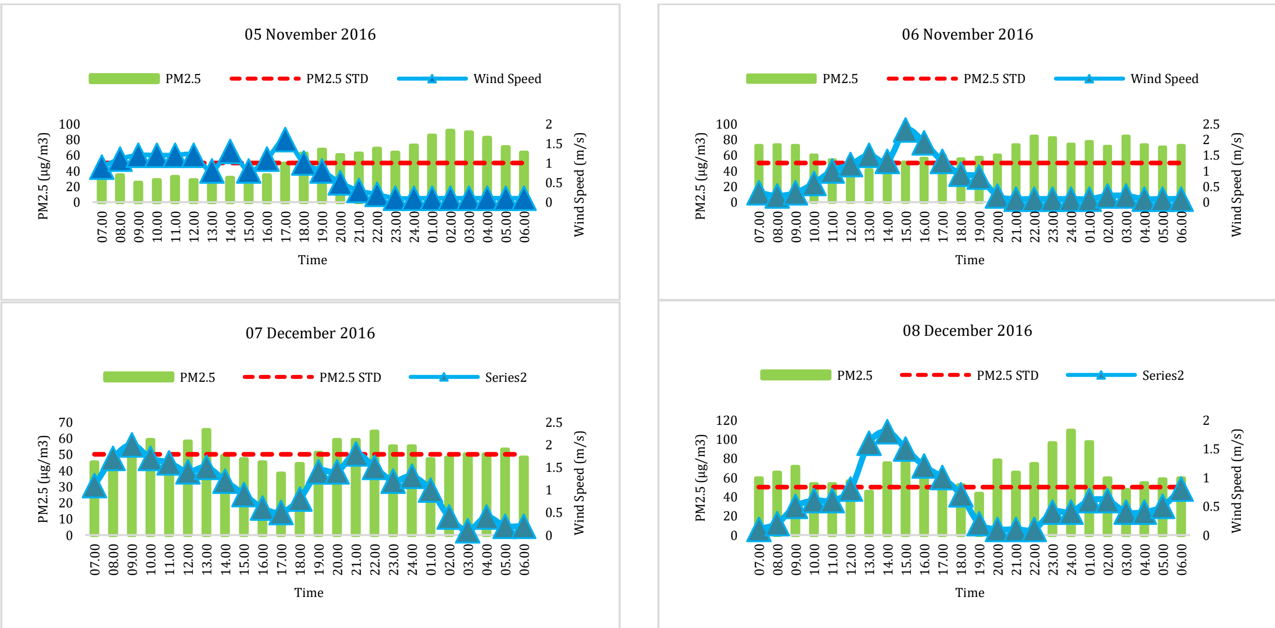

Fig. 2: Wind speed and $PM_{2.5}$ relationship

3.7. Regression

From Fig. 6, the Scatter plot and regression study suggest that NO_2, SO_2, and Relative humidity have a strong and positive correlation with $PM_{2.5}$ while other meteorological variations such as planetary boundary layer, wind speed, and temperature have a negative correlation with the $PM_{2.5}$ in the most period of study.

Fig. 3: Temperature and $PM_{2.5}$ relationship

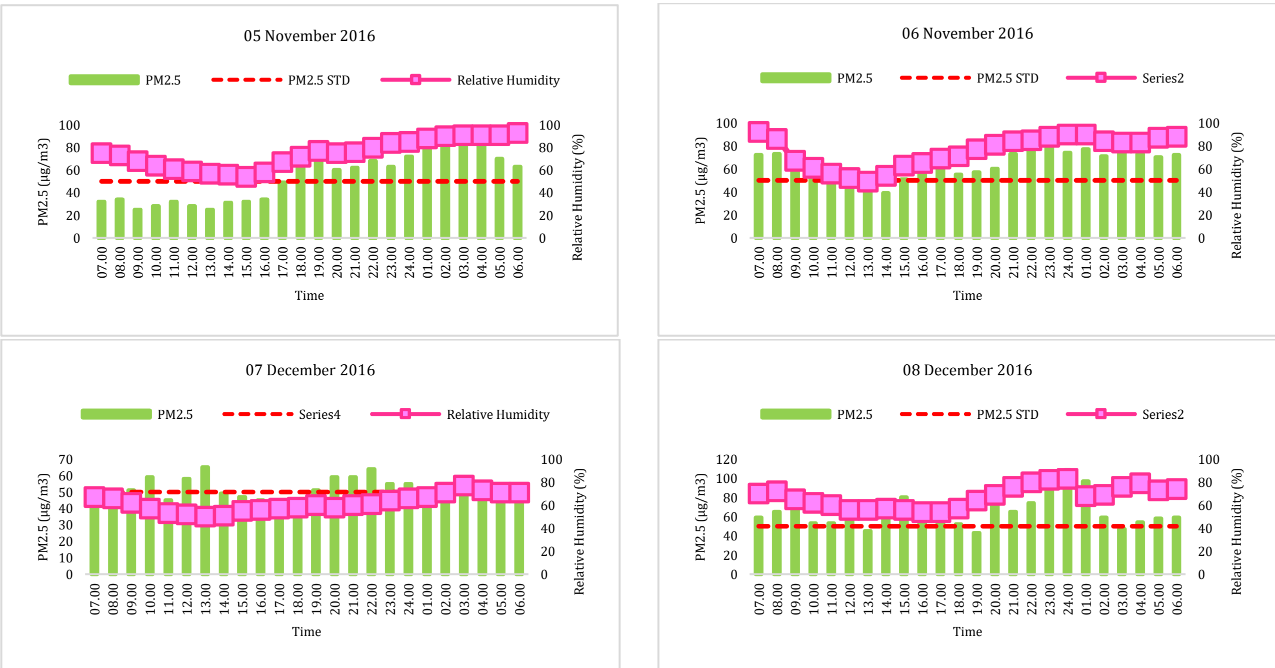

Fig. 4: Relative Humidity (R.H) and $PM_{2.5}$ relationship

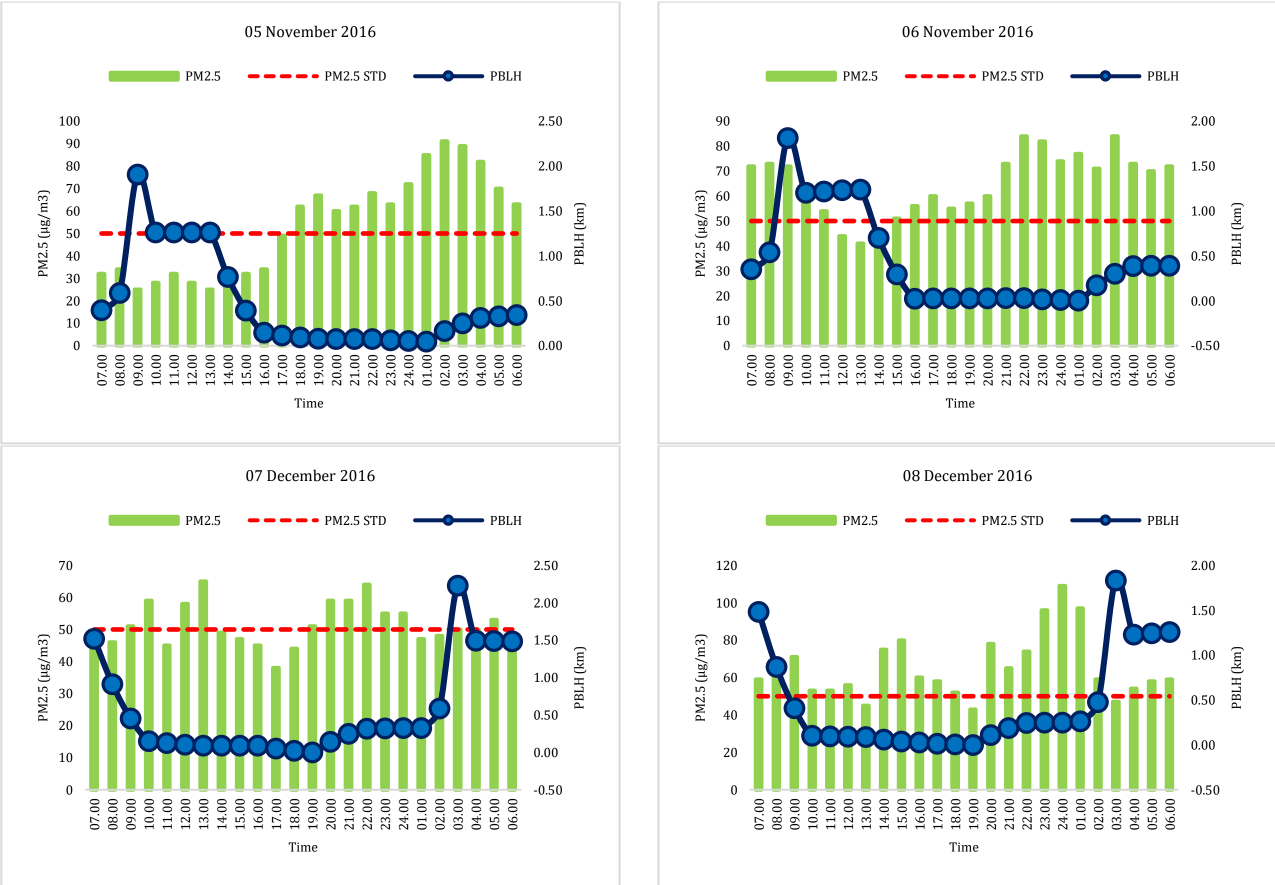

Fig. 5: Planetary boundary layer height (PBLH) and $PM_{2.5}$ relationship

Table 1: Correlation coefficient value between $PM_{2.5}$ and meteorological parameter and precursor gases

Year	Month	Date	WS(m/s)	WD	T(°C)	R.H. (%)	PBLH (km)	NO_2(μg/m³)	SO_2 (μg/m³)
		04	-0.50	0.57	-0.16	0.55	-0.35	0.84	0.83
	Nov	05	-0.78	-0.53	-0.84	0.84	0.49	0.83	0.49
		06	-0.49	0.20	-0.65	0.73	0.38	0.26	-0.45
		21	0.14	0.34	0.11	-0.22	0.38	0.26	0.51
		07	0.41	0.18	0.06	-0.04	-0.20	0.12	0.00
		08	0.00	0.08	-0.14	0.40	-0.13	0.53	0.72
		09	-0.64	-0.13	-0.49	0.58	-0.06	0.83	0.53
		10	-0.36	-0.17	-0.21	0.24	-0.31	0.27	0.35
2016		11	-0.39	-0.15	-0.26	0.28	0.36	0.49	0.62
		12	-0.76	-0.31	-0.81	0.82	0.32	0.47	0.07
	Dec	13	-0.69	-0.46	-0.73	0.75	0.66	0.76	0.54
		14	0.25	-0.10	0.61	0.16	0.40	0.21	0.61
		14	0.25	-0.10	0.61	0.16	0.40	0.58	0.65
		19	-0.49	0.35	-0.70	0.75	0.37	0.80	0.60
		20	-0.29	0.15	-0.41	0.56	-0.07	0.57	0.70
		21	-0.27	0.25	-0.38	0.48	0.37	0.86	0.48
		25	-0.57	0.41	-0.63	0.67	0.32	0.70	0.58
		15	-0.31	0.27	-0.51	0.51	0.64	0.30	0.52
		25	0.01	0.25	-0.55	0.31	0.53	0.52	0.85
	Nov	29	-0.77	-0.43	-0.82	0.84	0.71	0.78	0.00
		30	-0.02	0.32	-0.02	0.03	-0.13	0.60	-0.09
2017		31	-0.70	0.06	-0.88	0.80	0.58	0.30	0.52
		11	-0.77	-0.07	-0.78	0.72	0.42	0.76	0.03
	Dec	22	-0.30	0.36	-0.78	0.67	0.78	0.11	0.19
		23	0.03	0.69	-0.50	0.60	0.41	0.54	0.27
		16	-0.27	-0.07	-0.09	0.28	-0.33	0.81	0.39
		17	-0.61	0.36	-0.82	0.79	0.47	0.87	0.60
	Nov	19	-0.40	0.11	-0.73	0.80	0.75	0.70	0.49
		21	-0.35	0.60	-0.48	0.49	-0.11	0.84	0.49
		22	-0.57	0.17	-0.64	0.58	0.41	0.57	0.04
2018		20	-0.66	0.26	-0.81	0.79	0.01	0.78	0.71
		21	-0.66	0.14	-0.34	0.41	0.79	0.62	0.83
		22	-0.02	0.17	0.17	-0.11	-0.51	0.67	-0.07
	Dec	25	-0.49	-0.20	-0.46	0.61	-0.39	0.81	-0.29
		26	-0.42	0.27	-0.67	0.88	0.27	0.67	0.80
		27	-0.40	-0.10	-0.69	0.73	0.87	0.25	0.54
		28	0.30	0.24	0.15	-0.33	-0.06	0.23	0.46

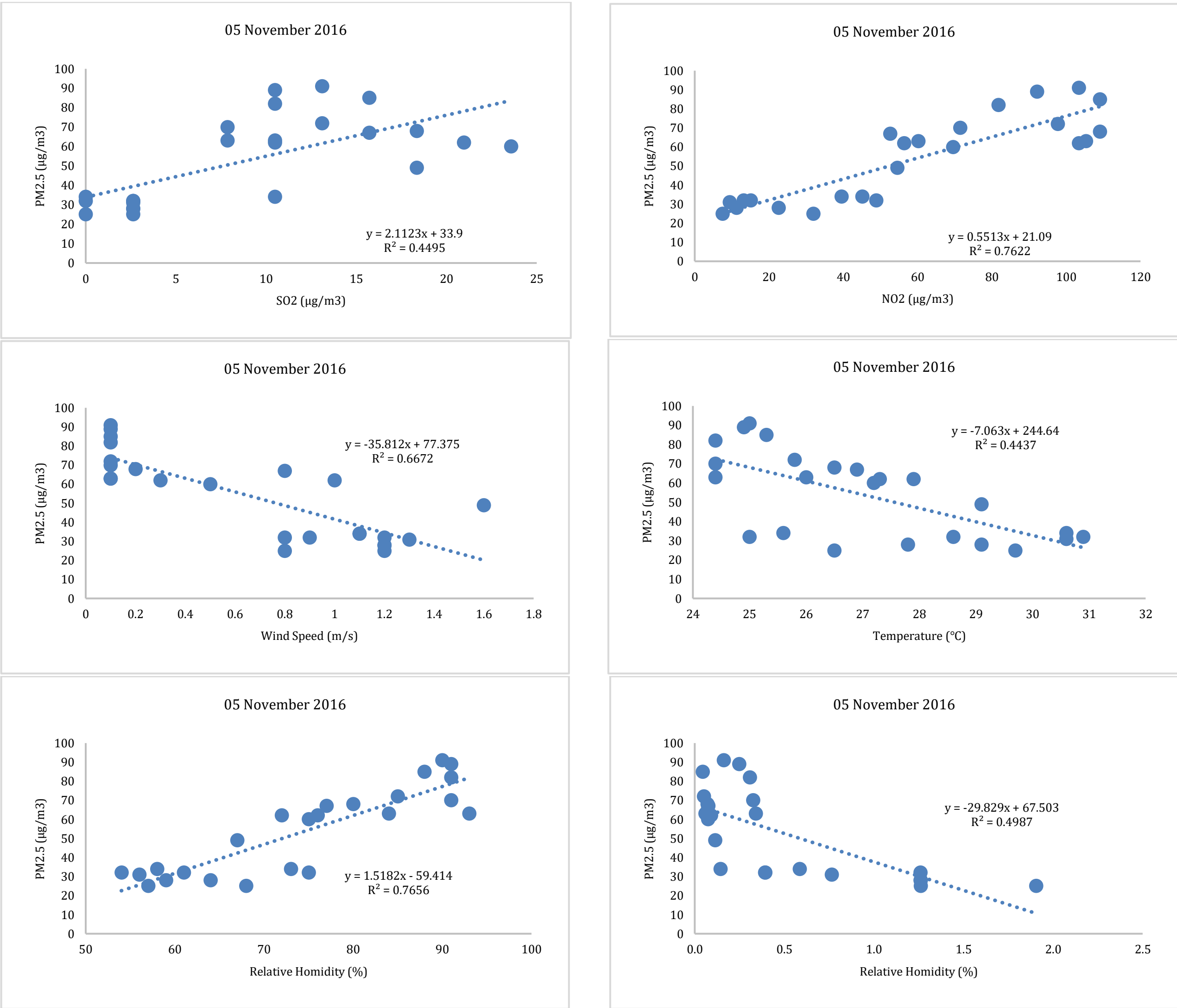

Fig. 6: Scatter plots of $PM_{2.5}$ and precursor gases and meteorological factors

4. Conclusion

The $PM_{2.5}$ concentration is potentially influenced by meteorological more than the precursor gas, and the $PM_{2.5}$ concentration has a strong positive relationship with relative humidity on most dates studied, and a strong negative relationship with wind speed and temperature, respectively. Moreover, $PM_{2.5}$ also has a medium relationship with the planetary boundary layer. However, in November 2016, there were negative relationships between SO_2 and $PM_{2.5}$ that should be investigated.

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Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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