Journal of Geoscience and Environment Protection, 2019, 7, 138-150
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Effect of Meteorological Factors on PM_{10} Concentration in Hanoi, Vietnam

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How to cite this paper: Dung, N. A., Son, D. H., Hanh, N. T. D., & Tri, D. Q. (2019). Effect of Meteorological Factors on PM_{10} Concentration in Hanoi, Vietnam. *Journal of Geoscience and Environment Protection, 7,* 138-150.
https://doi.org/10.4236/gep.2019.711010

Received: October 2, 2019
Accepted: November 23, 2019
Published: November 26, 2019

Abstract

According to the Ministry of Natural Resources and Environment, Hanoi city is currently facing the increased air pollution, especially particulate matter. This study examines the influence of meteorological factors including temperature, humidity and wind speed on PM_{10} concentration in Hanoi. The data used in this study include 24-h PM_{10} concentration data, hourly temperature, humidity and wind speed data in 2018 at three automatic air monitoring stations under Vietnam Environment Administration and Hanoi Natural Resources and Environment Department. The SPSS statistical analysis tools are utilized to analyze the correlation between PM_{10} concentration and meteorological factors through the Spearman (r) correlation coefficient. Additionally, the Independent-Sample T-Test is also employed to assess the difference in PM_{10} concentration in the period between dry season (from October to March) and wet season (from May to September). The results show that there is a trend of seasonal variation of PM_{10} concentration. Specifically, PM_{10} concentration recorded a higher value in winter and lower in summer. Different correlations between air pollutants and meteorological factors were also observed. PM_{10} concentration was inversely correlated ($r < 0$) with most of meteorological factors and there was a statistically significant difference (Sig. < 0.05) of PM_{10} concentration during dry and wetseason. This outcome has confirmed the important role of meteorological factors in the formation of air pollution with large variations in different seasons and geological areas.

Keywords

Meteorology, Temperature, Humidity, Wind Speed, PM_{10}, Air Quality

1. Introduction

Hanoi is one of the two largest cities in Vietnam. Besides the achievement on economic growth, the issue of environmental pollution, especially air pollution, is highly concerned. Recently, the urbanization rate in Hanoi rapidly increased, which has extended the pressure on the transport sector. In 2016, there were a total of 5 million motorcycles in the city. In case the average growth rate reaches 10% annually, Hanoi will have about 11 million motorcycles by 2025 (Sakamoto et al., 2018). Within the assessment on the application possibility of dispersion model to map the air pollutant concentrations in Hanoi, it is demonstrated that motorcycle is the major source of air pollution, accounting for 92% - 95% of total emissions. Moreover, it also contributes to 56% of NO_x, 65% of SO_2, 94% of CO and 86% PM_{10} emissions (Hung, 2010). Additionally, the rapid urban development has caused severe issues on environmental pollution, especially air pollution from particulate matter (PM). During the period of 2001-2004, the level of PM pollution in Hanoi was ranked at the second position among six cities studied in Asia (Oanh et al., 2006) and the pollution index has continued to remain at a high level in recent years (Ministry of Natural Resources and Environment, 2017).

Many scientific papers have indicated that air pollution, especially suspended particles from combustion processes in different forms, could cause severe impacts on human health. For PM_{10} (particles with an aerodynamic diameter smaller than 10 μm), the research of Katsouyanni et al. (1997) conducted in 29 European cities in 1997 has shown that a 10 μg/m^3 increase of PM_{10} concentration in air environment was associated with a 0.68% increase in all-cause daily mortality. Especially, the rate of cardiovascular disease has increased by 0.5% equivalent to a 10 μg/m^3 increase of PM_{10} concentration. Similarly, it is reported in Samet et al. (2000), a 10 μg/m^3 increase of PM_{10} concentration corresponding to a 0.5% increase of all-cause daily mortality has been recorded in 20 major urban areas in the US with a total of 50 million people. In Hanoi, Ly et al. (2017) found that high PM levels were associated with an increased risk of hospitalization for respiratory problems among children and more importantly the hospital admission increased as particle sizes decreased. Hai & Oanh (2013) reported $PM_{2.5}$ contributes most in PM_{10} in Hanoi as the ratio of $PM_{2.5}/PM_{10}$ ~0.76/0.08 implying the significant advert effects of PM on human health.

Weather conditions are an uncontrollable factor but also an extremely important element that influences air pollutant concentrations. In the context of climate change, the correlation between meteorological factors and air pollutants has raised a crucial concern (Fiore et al., 2012). Many studies on the effects of meteorological conditions on air quality have been well reported. The research of Giri et al. (2008) has presented that wind speed and humidity are significant factors affecting PM_{10} concentration. The Pearson correlation coefficient between PM_{10} concentration and humidity has resulted in an inverse correlation, thus exhibited a washing effect in the area (when the humidity increases, the

PM_{10} concentration decreases). On the other hand, the correlation coefficient between PM_{10} concentration and wind speed has given positive coefficient implying wind speed contributing to the increase of PM_{10} concentration. In Japan, Wang & Ogawa (2015) have utilized the analysis of Spearman correlation coefficient and indicated that $PM_{2.5}$ concentration, temperature and humidity have a negative correlation. Regarding wind speed, $PM_{2.5}$ shows positive correlation when wind speed is larger than 3 m/s or inverse correlation while wind speed is less than 3 m/s. In China, Zhang et al. (2015) have demonstrated the important role of meteorological factors in the formation of air pollution with remarkable changes in seasonal concentration and geological areas. Besides, the Spearman correlation analysis also reveals that $PM_{2.5}$ and PM_{10} dust are inversely correlated with wind speed.

Although the relationships between meteorological factors and air pollution have been investigated in the literature worldwide, until now, nationally, very few studies have reported on the influence of meteorological conditions on the city's urban air quality in general and PM pollution in particular. In order to initially understand the relationship between local meteorology and concentrations of pollutants, this study aims to examine the impacts of meteorological factors on urban air pollutants. This study also evaluates the linkages between meteorological factors such as temperature, humidity, wind speed and PM_{10} concentration in Hanoi city and to characterize the influence of meteorological parameters on PM_{10} pollution episodes in Hanoi.

2. Materials and Method

2.1. Description of Study Site

Hanoi is the capital of Vietnam with an area of 3358 km^2 (after the administrative expansion in 2008) and more than 7.4 million people (2017). It is expected that Hanoi will have an area of 13,463 km^2 and approximately 15 million people by 2020 (General Statistics Office of Vietnam, 2018). Hanoi is situated in the Northwest of the center of the Red River Delta, characterized by a tropical monsoon climate, with an explicit difference between wet and dry seasons (Bui et al., 2018). The wet season starts from mid-April to the end of October, but heavy precipitation mainly in July and August. Besides, the air masses from North and Northeast China normally bring a cold and dry climate from October to December. From January to March or April, the air masses with high humidity move across the Pacific Ocean to Northern Vietnam and lead to fog, low clouds and drizzle. Additionally, April and October have many unusual characteristics during the time between seasons, thus they are often classified as seasons of transition (Hien et al., 2002).

2.2. Data Collection

In order to assess the influence of meteorological factors on PM_{10} concentration in Hanoi, the data includes hourly meteorological factors (temperature, humidity and wind speed) and 24-h PM_{10} concentration collected at three automatic air quality monitoring stations in 2018 (Table 1). NVC Station and MK Station are located near busy road Nguyen Van Cu and National Highway 32 respectively with very high traffic density, while TY3 Station is in a residential area surrounded by internal roads with light traffic. The three air monitoring stations are in different directions representing various predominant urban traffic characteristic associated with high, medium and low density (Figure 1). The concentration of PM_{10} was measured in NVC station using Orthogonal Light Scattering 90˚ method while Beta-ray absorption method were used in TY3 and MK station. Weather Monitor (from ThiesClima for NVC station and Vaisala for

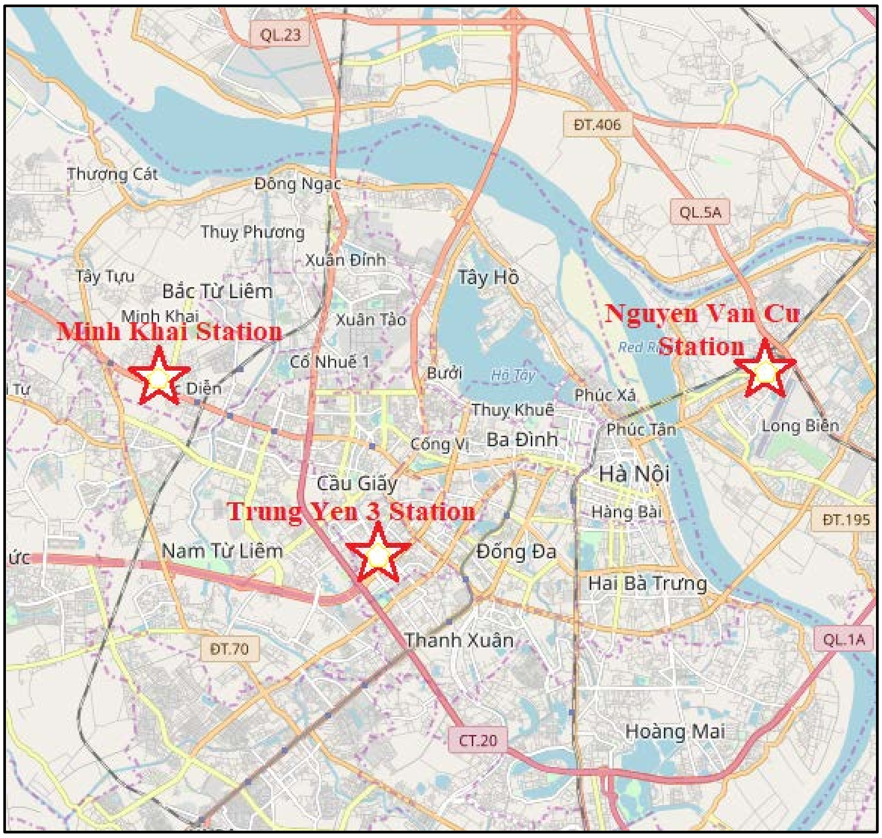

Figure 1. A map of study site ("Hanoi". Map. *Google Maps*. Google, 22 August 2019. Web. 22 August 2019).

Table 1. Summary information of air quality monitoring stations.

Site	Site Name	Coordinates	Site Characteristic	Inlet Height (from Ground)
Station of Centre for Northern Environmental Monitoring (CEM), No.556 Nguyen Van Cu Street, Long Bien District	NVC Station	21˚2'58.43"N 105˚52'55.83"E	Roadside	PM: 3 m
Station of Hanoi Environmental Protection Agency, No.17 Trung Yen 3, Trung Hoa Street, Cau Giay District	TY3 Station	21˚0'54.22"N 105˚48'0.17"E	Mixed	PM: 23.5 m
Station of Minh Khai Ward People Commitee, No.242U Minh Khai Street, Hai Ba Trung District	MK Station	20˚59'41.91"N 105˚51'22.07"E	Roadside	PM: 4.5 m

TY3 and MK station) was installed at roof top of each station providing essential weather conditions such as temperature, relative humidity and wind speed. The study was implemented in two seasons: dry season (from October to March) and wetseason (from April to September).

2.3. Methodology

The data were categorized in different data sets in order to assess the influence of meteorological factors on PM_{10} concentration using spreadsheets (Excel) and statistical analysis software (SPSS V.20). Means, standard deviations, and box plots were utilized to demonstrate the differences between categories. The statistical tools SPSS (Statistical Package for Social Sciences) is used to assess the correlation between PM_{10} concentration and meteorological factors through the Spearman correlation coefficient (r). The statistically average difference of PM_{10} concentration during dry and wet season has also constructed to show the average difference between two overall variables (Independent sample T-Test). The Sig. value of the Independent sample T-Test has the probability $\alpha = 0.05$ and the reliability is 95%. When the Sig. < 0.05, there is a difference in the mean of meteorological factors and PM_{10} concentration in the two overall variables (dry and wet seasons), conversely, in case of the Sig. ≥ 0.05, there is the similarity between the mean of the two overall variables.

3. Results and Discussions

3.1. Meteorological Characteristics and PM_{10} Concentration Variations

In 2018, the meteorological factors have indicated that the average temperature stays at a range of 24.2˚C - 25.3˚C. The highest temperature reaches at 36.6˚C in NVC Station (July 2018), the lowest temperature is measured at 8.0˚C in TY3 Station (January 2018). The annual average humidity is about 79%, the high value of humidity during dry season lasts from April to September with an annual average value of over 80%. The dampness month is from July to August with humidity around 80% - 95%. During the winter months, there are low humidity level and rainfall, the average humidity per month ranges from 75% to 80%. Moreover, the prevailing wind direction in Hanoi is the Southeast, the average wind speed stays at 1.5 m/s in 2018 (**Table 2**).

The monitoring results of the annual average PM_{10} concentration in 2018 at three automatic air quality monitoring stations have exceeded the permitted limit specified in the National Technical Regulation on Ambient Air Quality (QCVN 05:2013/BTNMT) (**Figure 2**). In particular, PM_{10} concentration exceeds 1.06 time (NVC Station) to 2.00 times (MK Station) compared to the standard allowed. It can be seen that the PM_{10} concentration in Hanoi has gone up to 156.1 - 283.9 μg/m^3 in some specific days of 2018 with 3.12 - 5.68 times higher than the QCVN 05:2013/BTNMT.

The changes of monthly average PM_{10} concentration in 2018 clearly show the differences over months of the year (**Figure 3**). The high PM_{10} concentration is

Table 2. Descriptive statistics of PM_{10} concentration, temperature, humidity and wind speed.

		PM_{10}	Temperature	Wind Speed	Humidity
		(μg/m³)	(˚C)	(m/s)	(%)
NVC Station	**N (day)**	**365**	**365**	**365**	**365**
	Mean	53.2	25.3	1.5	79.3
	Median	49.0	26.2	1.3	81.5
	Std. Deviation	35.9	5.3	0.6	9.8
	Minimum	3.0	9.8	0.7	40.5
	Maximum	283.9	36.6	3.4	95.8
TY3 Station	**N (day)**	**360**	**360**	**360**	**360**
	Mean	63.6	24.2	1.5	66.3
	Median	61.2	24.8	1.4	68.5
	Std. Deviation	20.2	5.7	0.4	12.0
	Minimum	5.7	8.0	0.4	19.9
	Maximum	156.1	35.7	3.1	90.0
MK Station	**N (day)**	**358**	**358**	**358**	**358**
	Mean	100.7	24.2	0.4	69.1
	Median	92.9	24.7	0.4	70.0
	Std. Deviation	36.5	5.2	0.2	11.9
	Minimum	21.4	11.4	0.1	26.7
	Maximum	276.4	35.6	1.1	91.2

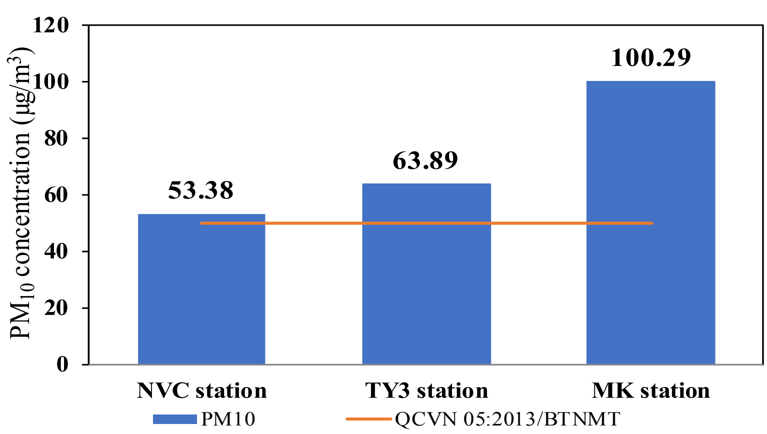

Figure 2. Comparasion of PM_{10} concentration at different stations.

mainly during dry months (October to March), the remaining months have lower PM_{10} concentration.

Figure 4 compares the mean PM_{10} concentration during dry and wetseason. The results showed a clear difference in PM_{10} concentration at different monitoring sites in both seasons, with a higher concentration in dry season and lower

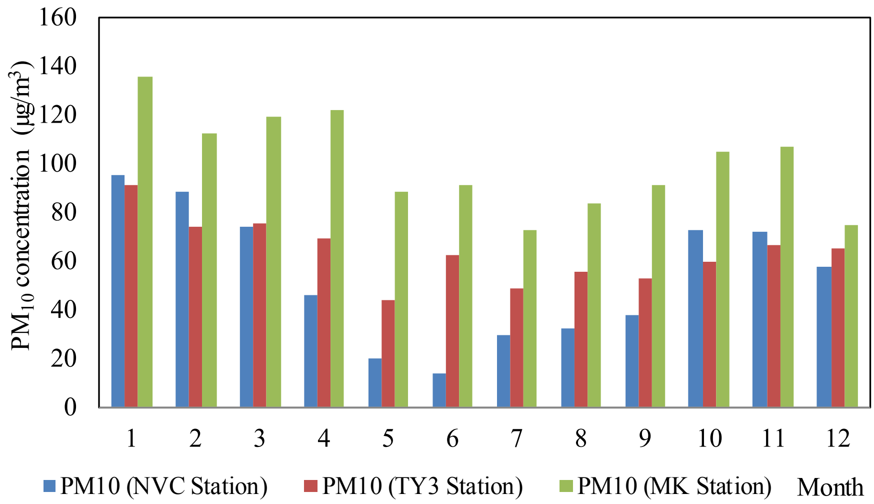

Figure 3. Monthly mean PM_{10} concentration at different stations.

in wet season. This result is also consistent with the studies of Zhao et al. (2009), Padro-Martinez et al. (2012), Schleicher et al. (2013), Zhang et al. (2015), Li et al. (2017), in particular, these studies have demonstrated that air pollutant concentrations such as $PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 and O_3 tend to vary significantly, and the largest concentration in winter and the lowest concentration in summer are caused by changes in the height of boundary layer and atmospheric conditions from season to season.

3.2. Correlation between PM_{10} Concentration and Meteorological Factors

The evaluation of the Spearman correlation coefficient between PM_{10} concentration and meteorological factors such as temperature, humidity and wind speed (**Table 2**) have indicated that the correlation coefficients are all inversely correlated at three monitoring sites. Thus, when the temperature, humidity, wind speed increases, the average PM_{10} concentration decreases and vice versa. Wind speed has a negative correlation with the PM_{10} concentration due to major effects associated with dust dispersion and dilution (Clements et al., 2016). This inverse correlation may indicate the predominant presence of point-sources pollution (Chaloulakou et al., 2003). During winter, the particular change in temperature may be related to air temperature inversion that reduces the height of the atmospheric boundary layer and dust diffusion, therefore increases dust concentration (Gramsch et al., 2014). Moreover, humidity has different influences on particle size distribution, for small size particles, the moisture content is usually negatively correlated as shown by the evidence of washing effect (Giri et al., 2008; Kozakova et al., 2017).

The results of correlation evaluation displayed in **Table 3** with the significance level of Sig. < 0.01 and the reliability of 99% show that temperature and wind speed are negatively correlated with PM_{10} concentration and not high at NVC Station and TY3 Station. The correlation coefficients between PM_{10} concentration

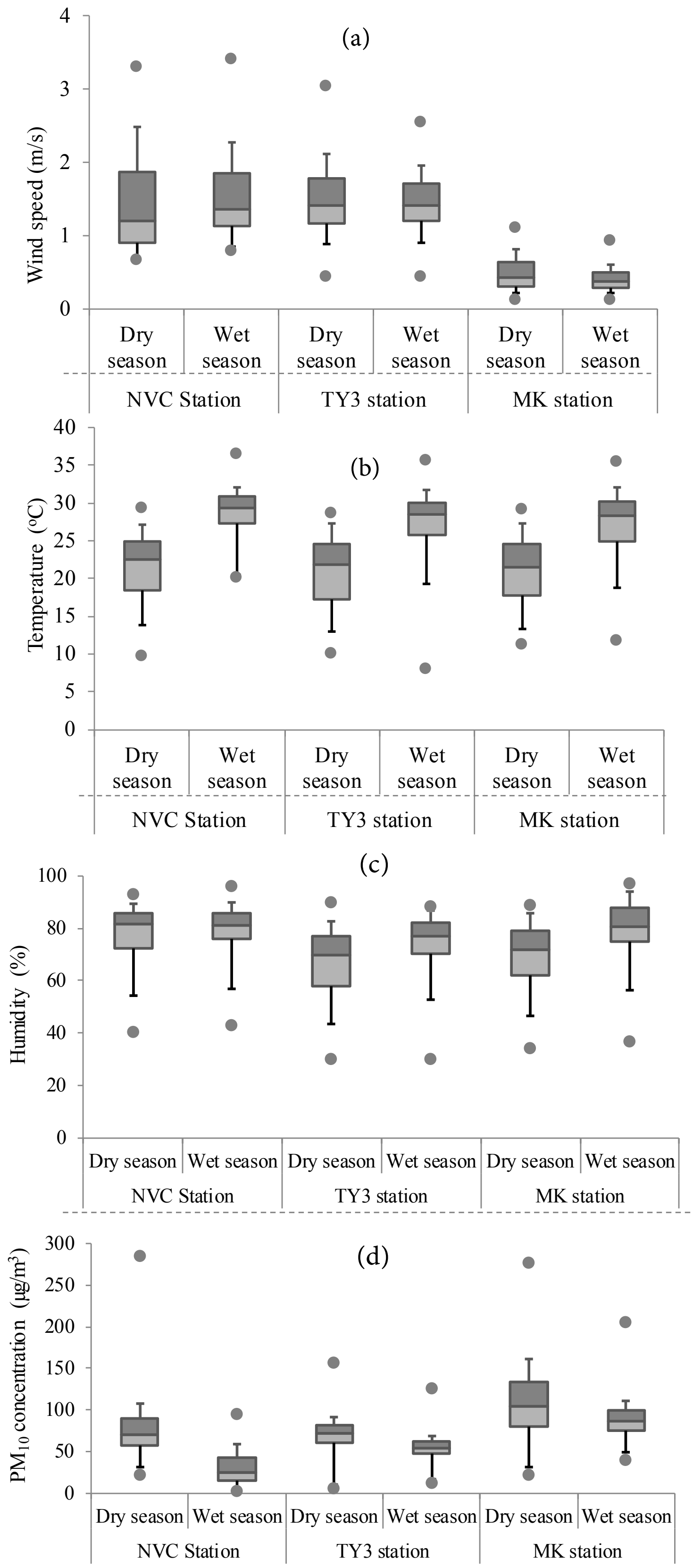

Figure 4. Seasonal variations of (a) Wind speed; (b) Temperature; (c) Humidity; (d) PM_{10} concentration.

Table 3. Spearman's coefficient of correlation between PM_{10} and selected meteorological factors.

Spearman Correlation			PM_{10}
NVC Station	Temperature	Correlation Coefficient (r)	−0.587**
		Sig.	0.000
		N	365
	Wind Speed	Correlation Coefficient (r)	−0.151**
		Sig.	0.004
		N	365
	Humidity	Correlation Coefficient (r)	−0.076
		Sig.	0.148
		N	365
TY3 Station	Temperature	Correlation Coefficient (r)	−0.281**
		Sig.	0.000
		N	360
	Wind Speed	Correlation Coefficient (r)	−0.232**
		Sig.	0.000
		N	360
	Humidity	Correlation Coefficient (r)	−0.017
		Sig.	0.753
		N	360
MK Station	Temperature	Correlation Coefficient (r)	−0.199**
		Sig.	0.000
		N	358
	Wind Speed	Correlation Coefficient (r)	−0.055
		Sig.	0.301
		N	358
	Humidity	Correlation Coefficient (r)	−0.204**
		Sig.	0.000
		N	358

**. Correlation coefficient at the significance level Sig. < 0.01 (99% reliability).

and temperature at NVC Station and TY3 Station are −0.587 and −0.281, respectively, and the correlation between PM_{10} concentration and wind speed is highest at TY3 Station (−0.232). At MK station, temperature and humidity are inversely correlated with PM_{10} concentration and fairly low at −0.199 and −0.204, respectively. According to the Giri et al. (2008), the low correlation coefficient between PM_{10} concentration and meteorological factors has demonstrated the competition of two mechanisms, the first is the atmospheric dispersion (dust particles are removed from air pollution through the process of dry and wet deposition by rain), and the second is the aerosolization diffusion from the surface (the air emission of particulate matter from street vehicles, industrial dust and soil dust). These linear correlations have clarified the fact that most of PM_{10} in the area has an anthropogenic origin.

The average difference test of two independent variations (Independent sample T-Test) during wet and dry season proves that the value of Sig. test < 0.05 (95% reliability) at monitoring sites has a statistical difference in the data sets of PM_{10} concentration, temperature, humidity and wind speed during two periods (Table 4).

The meteorological conditions (wind direction and wind speed) from Ha Dong station which is the representative station for Hanoi in 2018 have shown the prevailing wind direction is the Southeast, in which the winter has the dispersed wind direction and average wind speed lower than in the summer (Figure 5). Low

Table 4. Average PM_{10} concentration and selected meteorological factors in independent sample T-Test (95% reliability).

		Period	Day	Mean	Std. Deviation	Independent Sample T-Test (Sig.)
NVC Station	PM_{10}	Dry Season	182	76.56	33.70	0.00
		Wet Season	183	30.00	19.07	
	Temperature	Dry Season	182	21.62	4.53	0.00
		Wet Season	183	29.00	2.89	
	Wind Speed	Dry Season	182	1.42	0.59	0.03
		Wet Season	183	1.56	0.58	
	Humidity	Dry Season	182	78.30	11.14	0.04
		Wet Season	183	80.31	8.16	
TY3 Station	PM_{10}	Dry Season	178	71.75	21.41	0.00
		Wet Season	182	55.57	15.27	
	Temperature	Dry Season	178	21.02	4.65	0.00
		Wet Season	182	27.27	4.81	
	Wind Speed	Dry Season	178	1.49	0.45	0.01
		Wet Season	182	1.45	0.39	
	Humidity	Dry Season	178	67.38	12.59	0.02
		Wet Season	182	69.97	11.38	
MK Station	PM_{10}	Dry Season	175	110.41	43.02	0.00
		Wet Season	183	91.32	25.86	
	Temperature	Dry Season	175	21.06	4.41	0.00
		Wet Season	183	27.27	3.92	
	Wind Speed	Dry Season	175	0.47	0.22	0.00
		Wet Season	183	0.41	0.16	
	Humidity	Dry Season	175	68.38	12.49	0.01
		Wet Season	183	72.00	11.31	

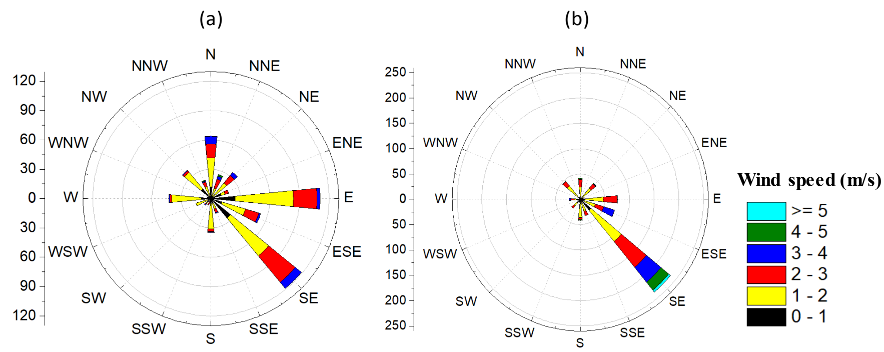

Figure 5. Wind rose data in 2018: (a) dry season and (b) wet season.

wind speed and different directions have led the slow PM_{10} dispersion thus increased air pollution. The study of Giri et al. (2008) has also indicated that wind speed is an important factor for the increase of PM_{10} concentration in the air environment at Kathmandu valley, Nepal. The research of Padro-Martinez et al. (2012) and Zhang et al. (2015) have also shown under conditions of low wind speed and high stable atmosphere, the horizontal diffusion and vertical disturbance are less prominent, whilst air pollutant concentration will significantly increase.

4. Conclusion

The study results from the influence of meteorological condition on PM_{10} concentration at three automatic air quality monitoring stations in Hanoi in 2018 has revealed that meteorological factors such as temperature, humidity and wind speed are inversely correlated with PM_{10} concentration in both dry and wet season. Wind speed and temperature are the most two crucial factors affecting PM_{10} concentration and also indicating a better correlation with PM_{10} compared to humidity. Besides, PM_{10} concentration tends to be higher during winter time, with little precipitation (from October to March), low temperature, calm wind and low relative humidity.

In this study, the findings have indicated the effects of temperature, humidity and wind speed on PM_{10} concentration. For future research, it is essential to conduct further investigation on the influence of other meteorological factors with different spatial and temporal variability, especially the influence of atmospheric pressure in order to have more accurate assessments about the major causes of air pollution in Hanoi.

Acknowledgements

The authors gratefully acknowledge Vietnam Meteorological and Hydrological Administration, Vietnam Environment Administration and Hanoi Natural Resources and Environment Department for the data providing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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