Vietnam Journal of Science and Technology ***61*** *(3) (2023) 471-479*
doi:10.15625/2525-2518/16497

Concentrations of $PM_{0.1}$ and $PM_{2.5}$ at high polluting event days in Ha Noi and the effects of meteorological conditions

Vo Thi Le Ha, Van Dieu Anh, Nguyen Thi Thu Hien, Dao Duy Nam, Nghiem Trung Dung, Ly Bich Thuy*

School of Environmental Science and Technology, Hanoi University of Science and Technology, 1 Dai Co Viet, Hai Ba Trung, Ha Noi, Viet Nam

*Email: *thuy.lybich@hust.edu.vn*

Received: 28 August 2021; Accepted for Publication: 16 December 2021

Abstract. High levels of fine ($PM_{2.5}$) and ultrafine ($PM_{0.1}$) particles in the atmosphere can cause adverse effects on the environment and human health. This study aims at determining the mass concentrations of PM and meteorological influencing factors in high pollution event days in Ha Noi. Daily samples of $PM_{2.5}$ and $PM_{0.1}$ were collected at a mixed site in Ha Noi, Viet Nam, from the middle of October to December 2020. High pollution events (episodes) were determined based on $PM_{2.5}$ concentrations and analysed for their average concentration and intensity (number of days). The regression analysis of PM concentration against meteorological parameters and their correlation matrix were determined by R software, version 4.04. Seven episodes with criteria of $PM_{2.5} > 50$ µg/m^3 for at least two continuous days were recorded for the 2.5 sampling months. The daily $PM_{2.5}$ concentrations were in the range of 19 - 147 µg/m^3 with an average of 59.5 µg/m^3, while those of $PM_{0.1}$ varied from 2 to 13 µg/m^3 with an average of 6.1 µg/m^3. The investigated meteorological factors can explain for 70 % of $PM_{2.5}$ variations but only 47 % of $PM_{0.1}$ variations.

Keywords: $PM_{2.5}$, $PM_{0.1}$, high pollution events, correlation, regression analysis.

Classification numbers: 2.1, 3.1, 3.2, 3.3

1. INTRODUCTION

Particulate matter (PM), especially $PM_{2.5}$ (particles with equivalent diameters smaller than 2.5 µm) has been reported to be a serious air pollution problem in Viet Nam, particularly in Ha Noi in recent decades [1, 2, 3, 4, 5, 6]. The annual $PM_{2.5}$ were higher than the national ambient air quality standard (QCVN 05:2013/BTNMT) of 25 µg/m^3 and several times higher than the current recommended levels by WHO of 5 µg/m^3. Because of its small diameter, $PM_{2.5}$ can penetrate deep into the lung and cause several health problems. The World Health Organization announced that there were around 60,000 deaths linked to air pollution in Viet Nam in 2016 [7]. The Global Burden of Disease also estimated that exposure to $PM_{2.5}$ accounted for 806,900 disability-adjusted life years in Viet Nam in 2015 [6]. There have been several studies to assess

the public health due to $PM_{2.5}$ exposure in Ha Noi so far [8, 9, 10, 11]. In addition to health consequences, $PM_{2.5}$ also contributes to the reduction of visibility [3, 12].

Besides $PM_{2.5}$, $PM_{0.1}$ (particles with equivalent diameters smaller than 0.1 µm) is also of great concern because of their health impact [2]. The tiny size and greater specific surface area of $PM_{0.1}$ let it bring toxic substances to penetrate deeply and accumulate in different parts of the body and pose health impacts [13, 14].

The levels of $PM_{2.5}$ in Ha Noi depend on emission sources [1, 15, 16], meteorological conditions [2, 3, 5 15, 17, 18], long-range transport [3, 16], and secondary formation [1, 15, 16]. Because of the strong effect of meteorological conditions in the region, $PM_{2.5}$ concentration varied year-round and got higher levels in winter and spring with the highest levels at the end of the year [3, 16]. In Ha Noi, $PM_{2.5}$ concentrations also have been reported to reach high levels on some days (episode period) [2, 4]. The higher concentration of $PM_{2.5}$ can result in more negative effects on public health.

There is no official criterion to determine an episode period in Viet Nam. In this research, the $PM_{2.5}$ concentration of 50 µg/m^3, which is its daily limited level in the national ambient air quality standard (QCVN05:2013/BTNMT), is chosen as the criteria for an episode. Moreover, a minimum of two consecutive days are also proposed to decide an episode period.

This study investigated the occurrence of $PM_{2.5}$ and $PM_{0.1}$ in $PM_{2.5}$ episodes. Effects of meteorological conditions on those PM concentrations in the monitoring periods were investigated.

2. MATERIALS AND METHODS

2.1. Sampling campaign

The sampling campaign was carried out continuously from 14 October to 31 December 2021 on the top of a third-floor building, inside Ha Noi University of Science and Technology (HUST), Ha Noi, Viet Nam (21°00'20.8"N and 105°50'39.1"E) as shown in Figure 1. Information about Ha Noi's characteristics and meteorological conditions can be found in the studies of Hien et al. [17], Hai and Kim Oanh. [15], Ly *et al.* [2]. The sampling site is considered a mixed site representing air quality in an urban area affected by multi-emission sources rather than a single dominant source. This site is 120 meters from a small road, 250 meters from a big road and surrounded by communities. The site is affected by many activities including transportation, construction, education, domestic cooking, etc.

The sampling methods have been reported in detail in our previous research of Huyen et al. [19]. In short, samples of $PM_{0.1}$ were taken by a Nano sampler II, Model 3182, KANOMAX, which is divided into five-stage cascade impactors at a constant flow rate of 40 L/min. $PM_{2.5}$ samples were taken by a cyclone (URG-2000-30EH) with a flow rate of 16.7 L/min. Quartz filters with 55 mm and 47 mm in diameter were used to collect $PM_{0.1}$ and $PM_{2.5}$, respectively. The inlets were placed at 1.5 m above the rooftop of a three-floor building, far from any obstructed subjects. Quartz filters were pre-burned at 350 ^oC for 2 hours to minimize chemical contaminants. They were weighed by an electronic microbalance at room conditions of 30 - 40 % humidity and 20 - 25 ^oC before and after sampling. A detailed description of sample filter weighing was presented in the study by Thuy *et al.* [5].

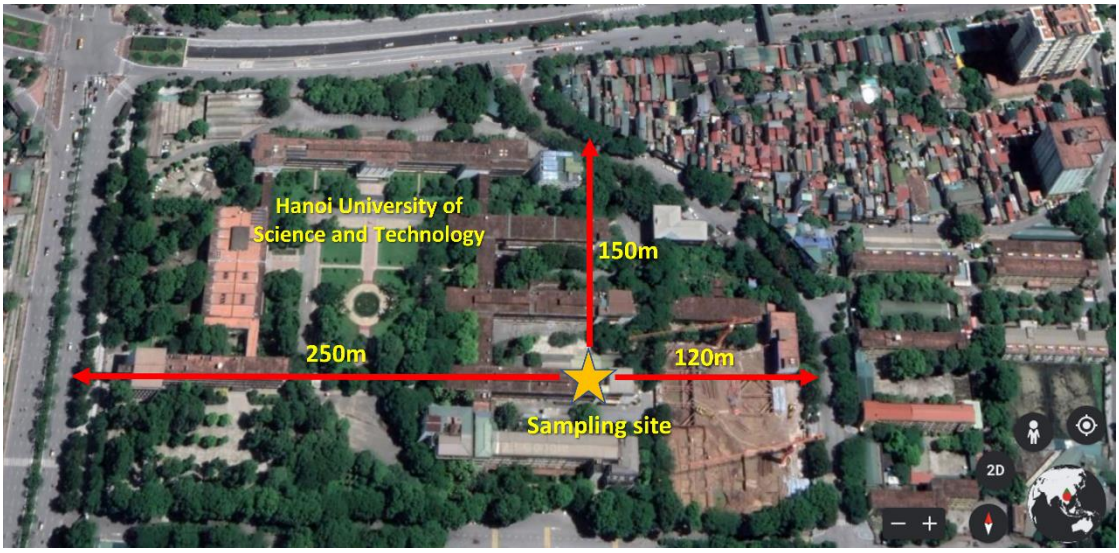


Figure 1. Sampling site at HUST, Ha Noi, Viet Nam.

2.2. Data analysis

Multiple linear regression analysis (MLR) is a statistical technique, which is most widely applied to study the influence of independent variables (meteorological factors) on dependent variables (concentration of pollutants) [20, 21]. The multiple regression model can be formulated as Eq. (1):

$$Ln\ C = LnK + \sum_i^n \alpha_i \times LnP_i\ + \varepsilon \quad (1)$$

where: K: coefficient; αi: the regression coefficients; Pi: dependent variables (meteorological factors)εi: error associated with regression; n: the number of independent variables.

Statistical significance (p) was fixed at $p < 0.05$. Shapiro-Wilk was used to test normal distribution. Once non-normal distributions were found, Spearman rank correlation coefficients would be applied to determine the correlation as the method is for non-parametric parameters.

The regression analysis of PM concentration against meteorological parameters and their correlation matrix were determined by R software, version 3.63. The meteorological parameters including precipitation (Pr), wind speed (Ws), temperature (T), relative humidity (RH), and wind direction (W_d) were examined.

RESULTS AND DISCUSSION

3.1. Levels of $PM_{2.5}$ and $PM_{0.1}$ in high pollution episodes

Figure 2 shows the variations of $PM_{2.5}$ and $PM_{0.1}$ during the investigated period from 14/10/2020 to 31/12/2020. This period belongs to the dry winter period. Overall, the concentrations of $PM_{2.5}$ were in the range of 19 µg/m^3 to 146 µg/m^3, whereas the average $PM_{2.5}$ concentration was 60 µg/m^3, which was higher than the daily limited level in QCVN05:2013/BTNMT of 50 µg/m^3 and 4 times higher than WHO guideline of 15 µg/m^3.

The concentrations of $PM_{2.5}$ fluctuated largely during the investigated periods. Seven high pollution episodes (defined as periods with more than one day, in which, the concentration of

$PM_{2.5}$ > 50 µg/m^3) were observed during the sampling period. Periods and averages of $PM_{2.5}$ of these episodes were as following: the first (22/10-28/10) of 86 µg/m^3; the second (31/10 - 1/11) of 73 µg/m^3; the third (4/11 - 13/11) of 86 µg/m^3; the fourth (23/11 - 27/11) of 62 µg/m^3; the fifth (30/11 - 2/12) of 76 µg/m^3; the sixth (5/12 - 12/12) of 100 µg/m^3 and the seventh (20/12 - 28/12) of 82 µg/m^3, respectively. The average concentrations of $PM_{2.5}$ in each episode period ranged from 62 to 100 µg/m^3, about 1.2 - 2.0 times higher than the daily limited level in QCVN05:2013/BTNMT and 4.1 - 6.7 times higher than the daily recommended level in WHO guidelines. The intensity of an event lasted from a minimum of two days to 10 days. The periods with several pollution episodes in our study were similar to Ha Noi's highly polluted periods in earlier studies, where the northeast monsoon cycles were shown to cause a dozen multi-day pollution episodes between October and April [2, 3, 18]. The high levels of $PM_{2.5}$ during these episodes were attributed to unfavored meteorological conditions and long-range transport as highlighted in previous studies [2, 3, 18]. The periods that high pollution episodes happened in Ha Noi are different from those in the other countries in Lower Southeast Asia, in summer when the haze originated from the forest fire, peat combustion, crop residue burning and slash-and-burn agricultural practices [22, 23].

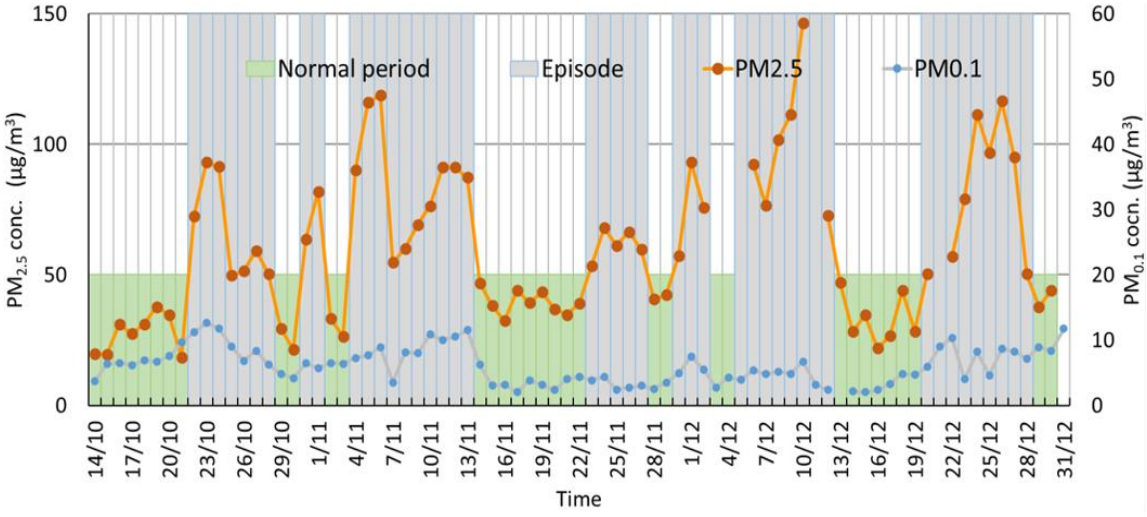


Figure 2. Variation of $PM_{0.1}$ and $PM_{2.5}$ from 14/10/2020-31/12/2020.

Concentrations of $PM_{0.1}$ ranged from 2 to 13 µg/m^3, with an average concentration of 6.1 µg/m^3. To our knowledge, there is no standard for $PM_{0.1}$ proposed by any agencies. However, our result is in the same range as those in Hanoi in the research of Thuy et al. (5 µg/m^3) [5] and Ha et al. (9 µg/m^3) [10]. Meanwhile, our concentration of $PM_{0.1}$ was higher than those in some European cities [24].

Even though several studies on the characteristics of $PM_{2.5}$ during high pollution episodes have been carried out in the region, the number of studies related to the characteristics of $PM_{0.1}$ during these periods is significantly scarce. Slightly similar trends with $PM_{2.5}$ variation were visibly found on the variations $PM_{0.1}$ in the first $PM_{2.5}$ episode event (22/10 - 28/10), the third (4/11 - 13/11) and the fifth (30/11 - 2/12). The trends of concentrations of $PM_{0.1}$ in the other periods were different from $PM_{2.5}$ variations. The reason for these differences is described to the effects of meteorological factors as explained in Section 3.3.

3.2. Correlations of PM concentrations with meteorological conditions

Table 1. The correlation of meteorological conditions with PM concentrations.

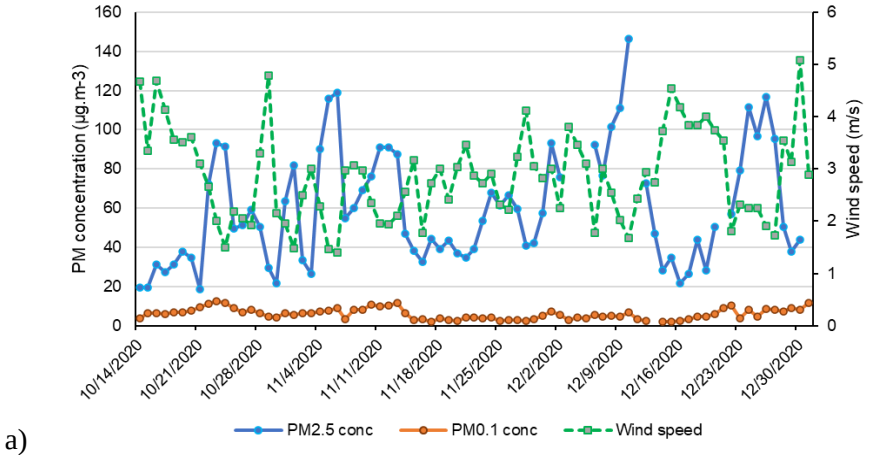
Parameter	Ws	T	RH	Wd	Pr
$PM_{0.1}$	-0.37	0.05*	-0.44	-0.42	-0.13*
$PM_{2.5}$	-0.69	-0.09*	-0.25	0.04	-0.55

**These values were non-statistical meaning p>0.05*

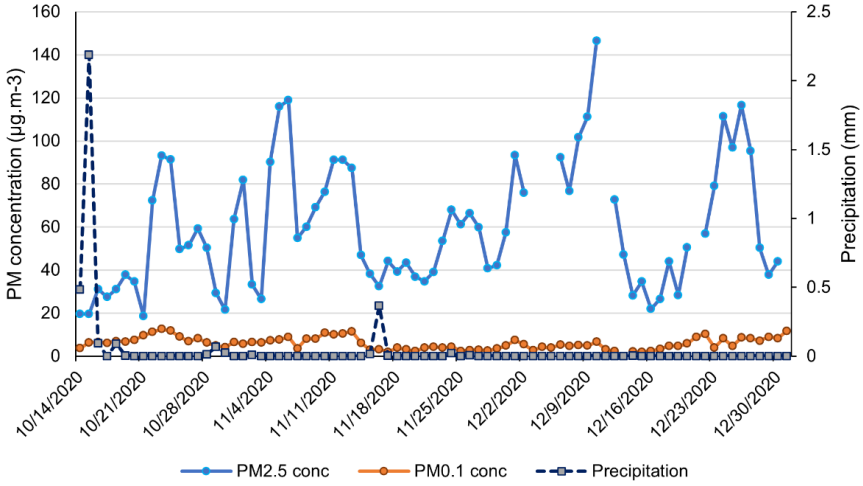
Meteorological factors including precipitation (Pr), wind speed (Ws), temperature (T), relative humidity (RH), and wind direction (W_d) were examined in this study. The inter-correlations between $PM_{2.5}$ and $PM_{0.1}$ concentrations and meteorological factors are shown in Table 1. The negative correlations between W_s and P_r versus $PM_{2.5}$ concentration suggest that increasing wind speed and rainfall levels can decrease the mass concentration of $PM_{2.5.}$ Good correlations between the concentration of $PM_{2.5}$ and Ws and P_r are further illustrated in Figure 3 (a, b). Those results are similar to the finding of Hien *et al.* [17] and matched well with the fact that stronger wind transports the pollutants further, leading to the reduction of $PM_{2.5}$ concentration and precipitation can wash out PM from the atmosphere. For $PM_{0.1}$, the effects of wind speed on its concentration are less significant than $PM_{2.5}$, and the effect of precipitation is not statistically significant. The low correlation between the concentration of $PM_{0.1}$ and Ws and P_r suggested the minor influence of these factors on $PM_{0.1}$. Surprisingly, $PM_{0.1}$ had moderate correlations with RH, which can facilitate the development of atmospheric particles, consequently forming larger particles [20]. In conclusion, the influences of some meteorological factors on the concentrations of $PM_{0.1}$ were negligible compared to those of $PM_{2.5}$, which agrees with earlier studies [5, 20].

3.3. Multiple Linear Regression (MLR) Analysis

The MLR analysis was carried out to determine the influencing factors such as Ws, Wd, Pr, RH, $Ws_{(p)}$, $Wd_{(p)}$ on the concentrations of PM. Detailed results from MLR analysis are summarized in Table 2. The regression results showed that influencing factors could explain 70 % of the variance of $PM_{2.5}$ concentration, while only 47 % of the variation of $PM_{0.1}$ concentration could be explained. It is clear that the meteorological factors more strongly influenced the variation of $PM_{2.5}$ than its of $PM_{0.1}$. The fact that the meteorological factors could explain the concentration fluctuation of $PM_{0.1}$ less efficiently than $PM_{2.5}$, which was consistent with earlier findings of Nghiem *et al.* [21] and Kozáková *et al.* [20]. Among meteorological factors, W_s and $W_{s(p)}$ were the most influencing factors. It is because strong winds generally dilute pollution in the atmosphere. However, these impacts are more significant on the $PM_{2.5}$ concentration. These results were relatively consistent with the correlation analysis mentioned above. The difference between $PM_{2.5}$ and $PM_{0.1}$ is due to removal mechanisms. $PM_{2.5}$ is removed predominantly by wet precipitation and has a long-suspended time, which also means that $PM_{2.5}$ can transport long distances, therefore, easily to be affected by W_s, $W_{s(p),}$ and W_d. In contrast, $PM_{0.1}$ is removed by diffusions and has a short residence time, which also means that its dispersion over long distances is limited.



a)



b)

Figure 3. Time series of meteorological parameters and $PM_{2.5}$ and $PM_{0.1}$ concentrations: a)Wind speed; b) Precipitation.

Table 2. Results of regression analysis.

arameter	Coefficient of multiple determination (adjusted R^2)	Slope	Variable (p<0,05)
$PM_{2.5}$	0.70	-17.32	Ws
		-0.10	Wd
		-11.75	$Ws_{(p)}$
		-0.55	RH
		-0.09	$Wd_{(p)}$
$PM_{0.1}$	0.47	-0.94	Ws
		-0.10	RH
		0.01	Wd

Note: $Ws_{(p)}$: Wind speed in the previous day; $Wd_{(p)}$: Wind direction in the previous day.

4. CONCLUSIONS

The present study found seven high pollution episodes of $PM_{2.5}$ during two and half months in dry winter in an urban area, in Ha Noi, Viet Nam. The trends of $PM_{0.1}$ were different from those of $PM_{2.5}$. The average concentrations of $PM_{2.5}$ during pollution episodes were 62-100 $\mu g/m^3$, about 1.2 - 2.0 times higher than the daily limited level in QCVN05:2013/BTNMT and 4.1 - 6.7 times higher than the daily recommended level in WHO guidelines. The intensity (number of days) of an event lasted from a minimum of two days to 10 days. Investigated meteorological factors can explain 70 % of $PM_{2.5}$ variations, in which Ws, and $Ws_{(p)}$ have predominantly influenced on $PM_{2.5}$ concentration. Meanwhile, the meteorological factors could explain 47 % of the concentration fluctuation of $PM_{0.1,}$ which was less efficient than $PM_{2.5}$. Ws was found as the most dominant influencing factor to $PM_{0.1}$ concentration. These results could convey messages to policymakers and stakeholders for air quality about the urgent requirement of actions for air quality improvement.

Acknowledgments. This work is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 105.99–2019.322. We also would like to thank Prof. Kazuhiko Sekiguchi, Saitama University for providing $PM_{2.5}$ and $PM_{0.1}$ samplers.

CRediT authorship contribution statement. Vo Thi Le Ha: Investigation, Writing original draft, Editing. Van Dieu Anh: Investigation, Editing, Nguyen Thi Thu Hien: Investigation, Editing. Dao Duy Nam: Sample Monitoring Supervision, Nghiem Trung Dung: Review, Validation. Ly Bich Thuy: Conceptualization, Methodology, Data Visualization, Editing, Funding acquisition.

Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. Makkonen U., Vestenius M., Huy L. N., Anh N. T. N., Linh P. T. V., Thuy P. T., Phuong H. T. M., Nguyen H., Thuy L. T. Aurela M., Hellen H., Loven K., Kouznetsov R., KyllÖnen K., Teinilä K. and Kim Oanh N. T. - Chemical composition and potential sources of $PM_{2.5}$ in Ha Noi, Atmos. Environ. **299** (2023) 119650.
2. Ly B-T, Matsumi Y, Nakayama T, Sakamoto Y, Kajii Y and Nghiem T-D. - Characterizing $PM_{2.5}$ in Ha Noi with New High Temporal Resolution Sensor, Aerosol Air Qual Res **18** (9) (2018) 2487-97.
3. Ly B-T, Matsumi Y., Tuan V. V., Sekiguchi K. Nguyen T. T, Pham C. T., Nghiem, T-D, Ngo I-H., Kurotsuchi Y., Nguyen T-H and Nakayama T. - The effects of meteorological conditions and long-range transport on $PM_{2.5}$ levels in Hanoi revealed from multi-site measurement using compact sensors and machine learning approach, J. Aerosol Sci. **152** (2020) 105716. https://www.sciencedirect.com/science/article/pii/S0021850220302019.
4. Bao Anh P. N., Delbarre H., Deboudt K., Dieudonné E., Tran D. N., Le Thanh S., Pelon J. and Ravetta F. - Key factors explaining severe air pollution episodes in Hanoi during 2019 winter season, Atmos. Pollut. Res. **12** (2021) 101068.
5. Thuy N. T. T., Dung N. T., Sekiguchi K., Thuy L. B., Hien N. T. T. and Yamaguchi R. - Mass concentrations and carbonaceous compositions of $PM_{0.1}$, $PM_{2.5}$, and PM_{10} at urban locations of Ha Noi, Viet Nam, Aerosol Air Qual. Res. **18** (2018) 1591-1605.
6. Cohen A. J., Brauer M., Burnett R., Anderson H. R., Frostad J., Estep K., Balakrishnan

K., Brunekreef B., Dandona L., Dandona R. Feigin V., Freedman G., Hubbell B., Jobling A., Kan H., Knibbs L., Liu Y., Martin R., Morawska L., Pope III C. A., Shin H., Straif K, Shaddick G., Thomas M., Dingenen R. V., Donkelaar A. V., Vos T., Murray C. J. L. and Forouzanfar M. H. - Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: An analysis of data from the Global Burden of Diseases Study 2015, the Lancet **389** (10082) (2017) 1907-1918.

7. WHO - More than 60,000 deaths in Vietnam linked to air pollution. WHO's News Release (2023) https://www.who.int/Vietnam/news/detail/02-05-2018-more-than-60-000-deaths-in-viet-nam-each-year-linked-to-air-pollution (accessed 10 March 2021).
8. Nhung N. T. T., Schindler C., Dien T. M., Probst-Hensch N., Perez L., Künzli N. - Acute effects of ambient air pollution on lower respiratory infections in Hanoi children: An eight-year time series study Environ, Int. **110** (2018). 139-148. https://doi.org/ 10.1016/j.envint.2017.10.02.
9. Vo H., Nguyen Hien., Nguyen A., Thai V. and Minoru Y. - $PM_{2.5}$ bounded PAHs in the indoor and outdoor air of nursery schools Ha Noi, Viet Nam and health implication, Vietnam J. Sci .Technol. **58** (2020) 319-327.
10. Ha V. T. L., Anh, V. D., Hien, N. T. T. and Nghiem T. D. - Indoor and outdoor relationships of particles with different sizes in at an apartment in Hanoi: Mass concentration and respiratory dose. Vietnam J. Sci. Technol. **58** (2020) 736-746. https://doi.org/10.15625/2525-2518/58/6/15237.
11. Luong L. M., Phung D., Sly P. D. and Morawska L, T. P. - The association between particulate air pollution and respiratory admissions among young children in Ha Noi, Viet Nam, Sci Total Environ **578** (2017) 249-255.
12. Van D. A., Tuan V. V., Hien N. T. T., Ha V. T. L., Nhung L. H., Thuy P. N. H., Prapat P., and Thuy L. B. - A review of characteristics, causes, and formation mechanisms of haze in Southeast Asia, Curr. Pollut. Rep. **8** (2022) 201-220.
13. Topi R. and Hilkka, T. - Overview of sources and characteristics of nanoparticles in urban traffic influenced areas, J. Alzheimer's Disease **72** (2019) 15-28.
14. Luke D., Tom H. and Lidia M. - A review of commuter exposure to ultrafine and its health effects, Atmos. Environ **45** (2011) 2611-2622.
15. Hai, C. D. and Kim Oanh, N. T. - Effects of local, regional meteorology and emission sources on mass and compositions of particulate matter in Ha Noi, Atmos. Environ. **78** (2013) 105-122.
16. Cohen D. D., Crawford J., Stelcer E., and Bac V. T. - Characterization and source apportionment of fine particulate sources at Hanoi from 2001 to 2008, Atmos. Environ. **44** (3) (2010) 320-328. https://doi: 10.1016/j.atmosenv.2009.10.037.
17. Hien P. D., Bac V. T., Tham H. C., Nhan D. D. and Vinh L. D. - Influence of meteorological conditions on $PM_{2.5}$ and $PM_{2.5-10}$ concentrations during the monsoon season in Ha Noi, Viet Nam, Atmos. Environ. **36** (2002) 3473-3484. https://doi.org/ 10.1016/S1352-2310(02)00295-9.
18. Hien P. D., Loc P. D. and Dao N. V. Air pollution episodes associated with East Asian winter monsoons, Sci. Total Environ **409** (23) (2011) 5063-8.
19. Huyen T. T., Sekiguchi K., Thuy L. B. and Dung N. T. - Assessment of traffic-related chemical components in ultrafine fine particles in urban areas in Viet Nam, Sci. Total

Environ **858** (2) (2023) 159869. https://doi.org/10.1016/j.scitotenv.2022.159869.

20. Kozáková J., Pokorná P., Černíková A., Hovorka J., Braniš M., Moravec P. and Schwarz J. - The association between intermodal ($PM_{1-2.5}$) and PM_1, $PM_{2.5}$, coarse fraction and meteorological parameters in various environments in central Europe, Aerosol Air Qual. Res. **17** (2017) 1234-1243. https://doi.org/10.4209/aaqr.2016.06.0242.
21. Nghiem T. D., Nguyen T. T. T., Nguyen T. T. H., Ly, B-T., Sekiguchi K., Yamaguchi R., Pham C. T., Ho Q. B., Nguyen M. T. and Duong T. N. - Chemical characterization and source apportionment of ambient nanoparticles: A case study in Ha Noi, Viet Nam, Environ. Sci. Pollut. Res. **27** (2020) 30661-30672. https://doi.org/10.1007/s11356-020-09417-5.
22. Chang C. H., Hsiao Y. L. and Hwang C. - Evaluating spatial and temporal variations of aerosol optical depth and biomass burning over southeast asia based on satellite data products, Aerosol Air Qual. Res. **15** (2015) 2625-2640. https://doi.org/10.4209/aaqr.2015.10.0589.
23. Thepnuan D., Chantara S., Lee C-T, Lin N-H. and Tsai Y. I. - Molecular markers for biomass burning associated with the characterization of $PM_{2.5}$ and component sources during dry season haze episodes in Upper South East Asia, Sci. Total Environ. **658** (2019) 708-722. https://doi.org/10.1016/j.scitotenv.2018.12.201.
24. Pennanen A. S., Sillanpää M., Hillamo R., Quass U., John A. C., Branis M., Hůnová I., Meliefste K., Janssen N. A. H., Koskentalo T., Castaño-Vinyals G., Bouso L., Chalbot M. C., Kavouras I. G. and Salonen R. O. - Performance of a high-volume cascade impactor in six European urban environments: Mass measurement and chemical characterization of size-segregated particulate samples, Sci. Total Environ. **374** (2007) 297-310. https://doi.org/10.1016/j.scitotenv.2007.01.002.