Vietnam Journal of Science and Technology ***62*** *(2) (2024) 335-345*

doi:10.15625/2525-2518/18373

Occurrence of $PM_{2.5}$ and $PM_{0.1}$ at high polluting event days in Ha Noi and health implication

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

School of Chemistry and Life Sciences, Hanoi University of Science and Technology, No.1 Dai Co Viet street, Hai Ba Trung district, Ha Noi, Viet Nam

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

Received: 26 May 2023; Accepted for Publication: 12 July 2023

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 health risks on pollution event days (episodes) in Ha Noi. Semi-daily samples (daytime and night-time) of $PM_{2.5}$ and $PM_{0.1}$ were collected at Hanoi University of Science and Technology, in December 2021. The daily $PM_{2.5}$ concentrations were in the range of 39 - 204 µg/m^3 (average of 119 µg/m^3). Those of $PM_{0.1}$ varied from 11 to 30 µg/m^3 (average of 22 µg/m^3). There is negligible change on daytime and night-time $PM_{0.1}$ concentrations, whereas those levels of $PM_{2.5}$ were remarkably different. $PM_{2.5}$ daytime concentrations were in the range of 39 – 205 µg/m^3 with an average of 106 µg/m^3. The level ranges of night-time were slightly wider which varied from 39 to 230 µg/m^3 (average of 136 µg/m^3). A prolonged episode of $PM_{2.5}$ (which is defined by the criterion of $PM_{2.5}$ > 50 µg/m^3) was found with an intensity of 26 days in December. During the pollution episode, the Monte Carlo simulation showed that respirable doses were the highest for the adult (above 21 years) for chronic effects, whereas the highest doses for acute were observed in the children (0-3 years), which has implications in the adverse health effects for sensitive groups. The sensitive analysis finds the concentration of PM to be the most influencing factor in inhalation dose estimation.

Keywords: $PM_{0.1}$, $PM_{2.5}$, high pollution events, health risk.

Classification numbers: 2.1, 3.1, 3.2, 3.3

1. INTRODUCTION

Particulate matter (PM) is a serious air pollution problem in Viet Nam, particularly in the Red River delta [1-6] which poses negative health consequences, with $PM_{2.5}$ and $PM_{0.1}$ being the most concerning pollutants. Several epidemiologic and toxicological studies demonstrated that $PM_{2.5}$ and $PM_{0.1}$ are of great concern because of their health impact [2, 5 - 7]. $PM_{2.5}$ could be inhaled and get deep into the lungs, even into the bloodstream, while $PM_{0.1}$ could easier penetrate further into pulmonary regions, resulting in increased toxicity due to its smaller size and larger surface area. Many studies have reported that there was a close link between exposure to PM with respiratory and cardiovascular hospital admissions, as well as pulmonary functions [8 - 11]

There have been several publications on the health impacts due to PM exposure globally. Kim *et al*. reported that exposure to high PM levels might lead to a range of diverse symptoms such as low birth weight in infants, pre-term deliveries, and infant deaths [12]. Kloog *et al*. emphasized that the health consequences of PM varied across different human groups, with generally higher risk in infancy, lower risk in healthy teenagers and younger adults, and rising risk from middle age to old age [13]. Brauer *et al*. observed that older adults, children, and those with heart or lung problems were more susceptible to PM than other categories [14]. In the case of $PM_{2.5}$ exposure, the children suffered from a high risk of respiratory diseases and a decrease of lung function [15].

In recent years, there has been increased attention towards air pollution events (episodes) in Viet Nam. The national ambient air quality standard in Viet Nam, known as QCVN 05:2013/BTNMT (NAAQS), regulates the daily concentration of $PM_{2.5}$ of 50 µg/m^3, which is about three times higher than the recommended daily value of WHO guideline of 15 µg/m^3. There were several days within a year in Ha Noi the concentrations of $PM_{2.5}$ exceeded NAAQS [2, 16, 17]. In addition, the requirement of emergency actions for air pollution has recently been required by the regulation for the first time. According to the Law on Environment Protection (2020), the central government is required to take emergency measures when air pollution reaches severe levels across provinces, regions, or borders and provincial authorities must act when pollution becomes severe in their areas [18]. Severe air pollution is defined by the Vietnamese air quality index (VN_AQI) of equal to or greater than 301 in three consecutive days. The VN-AQI of 301 will happen when the daily or hourly $PM_{2.5}$ concentration reaches 250.5 µg/m^3.

Studies about the health impact of PM in Viet Nam are scarce. There are some publications about health risks due to exposure to PM in ambient air, which reported an increase in hospital admissions due to exposure to high $PM_{2.5}$ in Ha Noi and Ho Chi Minh city [19, 20]. Another found a relationship between PM levels and hospital admissions for cardiovascular and respiratory diseases in adults in Hanoi, Quang Ninh, and Phu Tho provinces [21]. Vu *et al*. calculated the mortality cases in Ho Chi Minh City due to exposure to poor air quality [22]. Besides the PM concentrations, their chemical components (e.g., PAHs, trace elements) can exaggerate health influences [23 - 25]. Notably, to our knowledge, Viet Nam has no studies that have been conducted on the health consequences due to exposure of ambient particles during high-polluting events day. As a result, a deeper understanding of $PM_{2.5}$ and $PM_{0.1}$ related to health consequences in these periods is of great urgency in Viet Nam. Therefore, this study aims to better understand PM pollution during high pollution periods in Hanoi, focusing on $PM_{2.5}$ and $PM_{0.1}$, and to assess the health consequences according to age groups, thereby it could be helpful in improving regional air quality.

2. MATERIALS AND METHODS

2.1. PM monitoring

The sampling campaign was carried out continuously from 01 - 31 December 2021 on the rooftop of a third-floor building, in Hanoi University of Science and Technology, Ha Noi, Viet Nam, as shown in Figure 1. The samples were taken twice per day from 7 am to 6 pm to represent the daytime and 6.5 pm to 6.5 am the next day to represent the nighttime. The coordinates of the site are 21°00'20.8"N and 105°50'39.1"E. This site is considered as a mixed site, representing air quality in an urban area affected by multi-emission sources rather than a single dominant source. This site is about 100 to 300 m far from roads and surrounded by communities, affected by different activities including transportation, construction, education, domestic cooking, etc. Detailed information of the sampling site and sampling methodology is presented in the studies of Huyen *et al*. [17] and Vo *et al*. [25].

Samples of $PM_{0.1}$ were taken by a Nano sampler II (Model 3182, KANOMAX, Suita, Japan) 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, University Research Glassware Corp., Chapel Hill, NC, USA) with a flow rate of 16.7 L/min. Quartz filters (2500 QAT-UP, Pall Corp., USA) with 55 mm and 47 mm in diameter were used to collect $PM_{0.1}$ and $PM_{2.5}$, respectively. Field blanks were applied with a ratio of one blank per 10 samples. The inlets were situated at 1.5 m above the floor of a three-floor building, far from any obstructed subjects. Quartz filters were pre-burned at 350 ^oC for 2 hours to minimize the chemical contaminants. They were weighed by an electronic microbalance (Sartorius ME 5, Swiss) to an accuracy of 10^{-6} g. The microbalance is calibrated yearly. The filters including sampled filters and blank were conditioned at the same room conditions of 30 - 40 % humidity and 20 - 25 ^oC before and after sampling. Sampled filters and blanks were passed through an ionizing air blower to limit the effects of static electricity during weighing. All samplers were weighted with room blank three times. After sampling, quartz filters were placed in Petri dishes, kept in an airtight bag, and refrigerated at HUST for further analysis of chemical compositions. The weight concentrations are converted to normal concentrations of 25 ^oC, 1 atm.

The daily concentrations of $PM_{2.5}$ and $PM_{0.1}$ were calculated by averaging the value of the daytime sample and night-time samples, with correction factors of daytime samples of 11 hours and night-time samples of 12 hours. In case the daytime or night-time concentrations were missed, the daily values are decided based on the available samples.

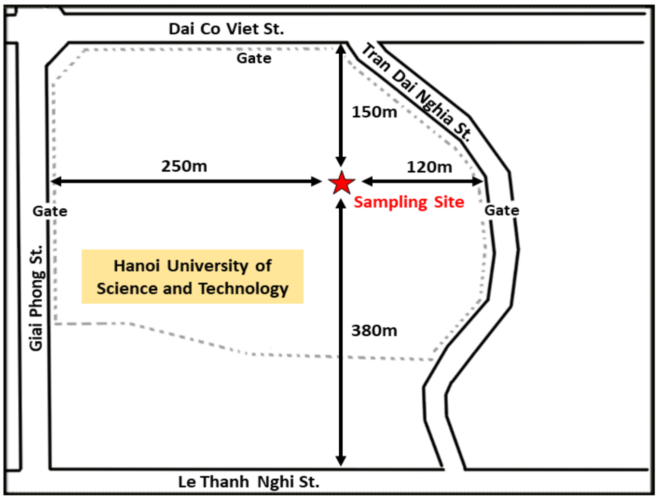

Figure 1. Sampling site at HUST, Ha Noi, Viet Nam.

2.2. Health risk analysis

To assess the health effects associated with respiratory particles ($PM_{0.1}$ and $PM_{2.5}$), daily respirable doses (ADD) were estimated in accordance with the US EPA model [26]. The ADD for respirable particles can be calculated by the following Equation [1]:

$$ADD = \frac{C * IR * ET * EF * ED}{BW * AT} \quad (1)$$

where C: $PM_{0.1}$ and $PM_{2.5}$ concentrations μg/m^3; IR: Inhalation rate (m^3/day); ET is the exposure time (h/day); EF is exposure frequency (d/year); ED is exposure duration (year) and AT is the average time (day).

@Risk software model version 8.0 was used for Monte Carlo simulation and sensitivity analysis.

3. RESULTS AND DISCUSSION

3.1. Concentrations of daily $PM_{2.5}$ and $PM_{0.1}$ in episodes

The daily concentrations of $PM_{2.5}$ and $PM_{0.1}$ are depicted in Figure 2. Data of daily $PM_{2.5}$ and $PM_{0.1}$ in December 2020 at the same site, which were presented in detail by Vo *et al*. [17] are also presented in Figure 2 for comparison.

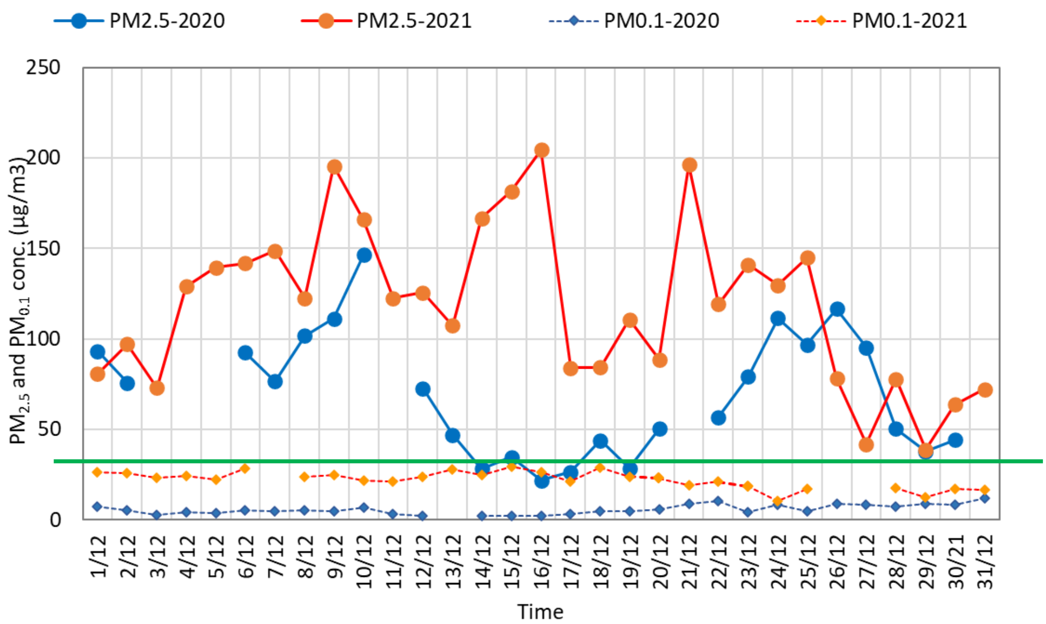

Figure 2. Variation of PM_{01} and $PM_{2.5}$ in December 2021 and 2020 in Ha Noi.

The green line presents a limited value to determine a pollution episode.

During the whole sampling period, the daily levels of $PM_{2.5}$ in December 2021 were in the range of 39 - 204 μg/m^3 with an average of 119 μg/m^3. This average level was approximately 2.5 times higher than the daily value of NAAQS of 50 μg/m^3. The range and average of daily $PM_{2.5}$

were higher than those in 2020 of 22 - 146 µg/m^3 with an average concentration of 70 µg/m^3 [17].

There were 29 days out of 31 days in December 2021 that the concentrations of $PM_{2.5}$ exceeded the NAAQS, almost double those in 2020 of 16 days [17]. These polluted days in 2021 are divided into two pollution episodes of which the most prolonged lasted up to 26 days, while the longest one in 2020 lasted only 8 days. Notably, the continuous 26 polluted days identified in this study were the longest episode in comparison with our previous studies in Ha Noi up to date [27]. This episode event lasted longer than most of the other periods occurring in SEA as shown in the study of Van *et al*. [28]. It is important to underline that the high levels of $PM_{2.5}$ during episodes in this region were attributed to sources, unfavored meteorological conditions, and long-range transport as mentioned in earlier studies [28, 29]. To investigate the reason for the prolonged episode with high $PM_{2.5}$ concentration, further study needs to be carried out. However, it is important to note that traffic activities were restricted for several months before December 2020 as well as before December 2021 because of COVID-19. Nevertheless, the investigated months in both years are not month of social distance because of COVID-19.

In contrast with the fluctuating trend of $PM_{2.5}$, the concentrations of $PM_{0.1}$ in both 2021 and 2020 were quite stable. However, the levels of $PM_{0.1}$ in 2021 were significantly higher than those in 2020. The levels in 2021 ranged from 11 to 30 µg/m^3 while those in 2020 were from 2 to 12 µg/m^3. The average value of those were 6 µg/m^3 and 22 µg/m^3 in 2020 and 2021, respectively. To our knowledge, there are no official guidelines in Viet Nam regarding permissible levels of $PM_{0.1}$. The concentrations of $PM_{0.1}$ in 2021 were not only higher than those at the same site in 2020 in the study of Vo *et al*. [25], but also higher than those in other sites in Ha Noi in the study of Thuy *et al*. (5 µg/m^3) [6] and Vo *et al*. (9 µg/m^3) [5]. Moreover, the levels of $PM_{0.1}$ in this study are also higher than those in other urban sectors in the world, such as in Phnom Penh (19 µg/m^3) [30], Chiang Mai (16.5 µg/m^3) [30], Beirut (14 µg/m^3) [31], Riau (12.4 µg/m^3) [30], Kuala Lumpur (9.3 µg/m^3) [30], Athens (7 µg/m^3) [32], Amsterdam (4 µg/m^3) [32], Shanghai (2.7 µg/m^3) [33]. A comprehensive study by Worradonrn *et al*. [34] in Southeast Asia also showed that the $PM_{0.1}$ levels in Ha Noi are more progressive than those in other investigated sites in SEA countries.

3.2. Daytime and night-time PM levels

The daytime and night-time concentrations of $PM_{2.5}$ and $PM_{0.1}$ in December 2021 are presented in Figure 3a and Figure 3b, respectively. It is interesting to note that whereas daytime and night-time $PM_{0.1}$ concentrations changed negligibly, those levels of $PM_{2.5}$ were significantly different. Particularly, daytime $PM_{2.5}$ concentrations were in the range of 39 - 205 µg/m^3 with an average of 106 µg/m^3. The level range of night-time was slightly wider which varied from 39 to 230 µg/m^3 (an average of 136 µg/m^3).

Despite the fact that human activities mostly happen in the daytime, nighttime concentrations of $PM_{2.5}$ still tend to be higher. Even on the first days in sampling periods, the values of $PM_{2.5}$ at night-time were about double those in the daytime. The same trend was not found for $PM_{0.1}$ concentrations. This higher $PM_{2.5}$ trend at night time is in line with observations by Ly *et al*. [2]. The high $PM_{2.5}$ levels at night are more often, which is ascribed to a temperature inversion, weak surface wind and low atmospheric convection. According to Hien *et al*., temperature inversion combined with a low speed of wind in winter led to the reduction of transporting/diluting PM in the atmosphere [35]. In addition, the greater stability trend of $PM_{0.1}$ concentrations than $PM_{2.5}$ in both daytime and night-time was in line with the previous discussion that the influence of several meteorological conditions on the levels of $PM_{0.1}$ was negligible in comparison to larger particle size [17, 36].

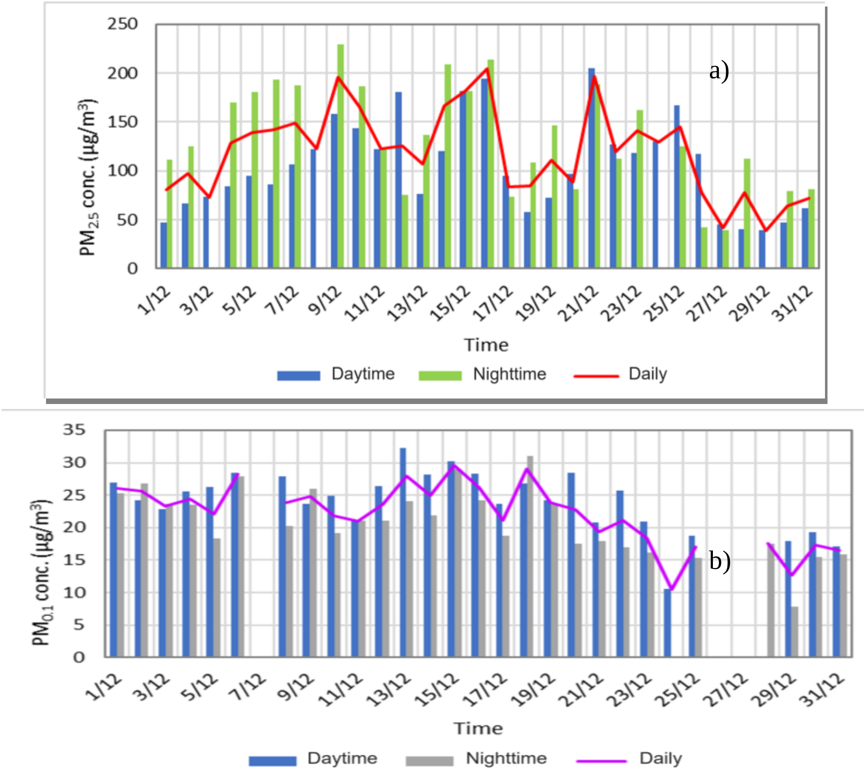

Figure 3. Daytime and night-time concentrations of: a) $PM_{2.5}$, b) $PM_{0.1}$.

3.3. Respirable dose estimation

In this study, health risk assessment was carried through estimating the daily dose (ADD) of $PM_{0.1}$ and $PM_{2.5}$ for chronic and acute effects according to different age categories based on the equation (1) in pollution episodes in the sampling period in 2021, which is demonstrated in Figures 4 and 5. Based on USEPA guideline for health risk assessment according to age group, exposure inhabitants are classified into six age groups: (0 - 3 years), (3 - 6 years), (6 - 11 years), (11 - 21 years), (21 - 60 years), and (over 60 years). The parameters (IR and AT) were based on the USEPA exposure handbook [26, 37], while the other parameters, such as ED, ET, and BW, were explored in the survey questions used during the sampling campaign. For example, the IR values were set at 8.9, 10.1, 12, 16.3, 15.7, and 12.6 m^3/day for (0 - 3 years), (3 - 6 years), (6 - 11 years), (11 - 21 years), (21 - 60 years), and (over 60 years), respectively; an AT was set of 25550 days as the lifetime of 70 years as chroric effect or multiplying of ET*EF*ED as acute effect [26, 37]. ET values from 500 questionnaires were 1.5; 1.5; 2.5; 3; 3; 2.5 hours/day; ED was 3, 6, 11, 21, 60, 65 years and BW was at 10.6, 18.4, 25.4, 45.2, 55.3, 57.8 kg for corresponding age categories: (0 - 3 years), (3 - 6 years), (6 - 11 years), (11 - 21 years), (21 - 60 years) and (over 60 years), respectively.

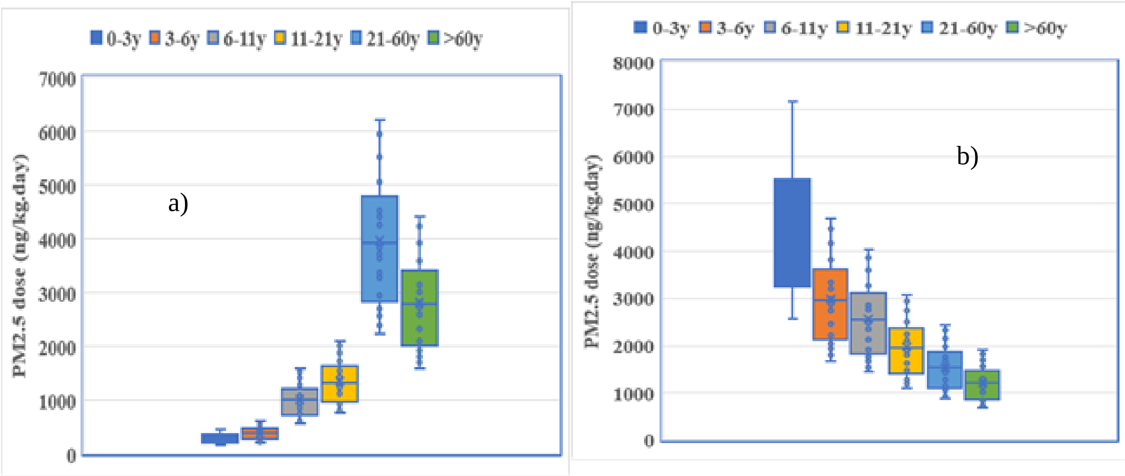

Figure 4. Respirable doses of $PM_{2.5}$: a) chronic effect; b) acute effect.

During the pollution episode in 2021, it is found that the daily respirable doses for chronic effects increase with age categories, whereas those for acute effects decrease. For chronic effects, the respirable daily doses increased from 293 to 3609 ng/kg.day and from 52 to 706 ng/kg.day for $PM_{2.5}$ and $PM_{0.1}$ with increasing ages, respectively. For acute effects, those decreased from 4151 to 1211 ng/kg.day and from 811 ng/kg.day to 216 ng/kg.day for $PM_{2.5}$ and $PM_{0.1}$, respectively, corresponding to the term of ages (0 - 3, 3 - 6, 6 - 11, 11 - 21, 21-60, and above 60 years). The doses for the age group below 21 years were 1.5- 15.5 times higher than those for adults above 21 years for acute effects, whereas those for adults above 21 years were 2 to 3 times higher than those for groups under 21 years for chronic effects. The different doses between acute and chronic effects as well as among age groups were attributed to the variation of exposure time, exposure duration, inhalation rate and body weight. It is interesting, the highest doses were seen in children (0 - 3 years) for acute effects and in the adults with group age (21 - 60 years) and (above 60 years) for chronic effects. It is likely that the children were more sensitive to acute effects than the adults, while the adults above 21 years old were getting more worsen influenced by chronic effects. Higher doses for inhalation of $PM_{2.5}$ were obtained in comparison with those for $PM_{0.1}$, which was assigned to higher $PM_{2.5}$ concentrations.

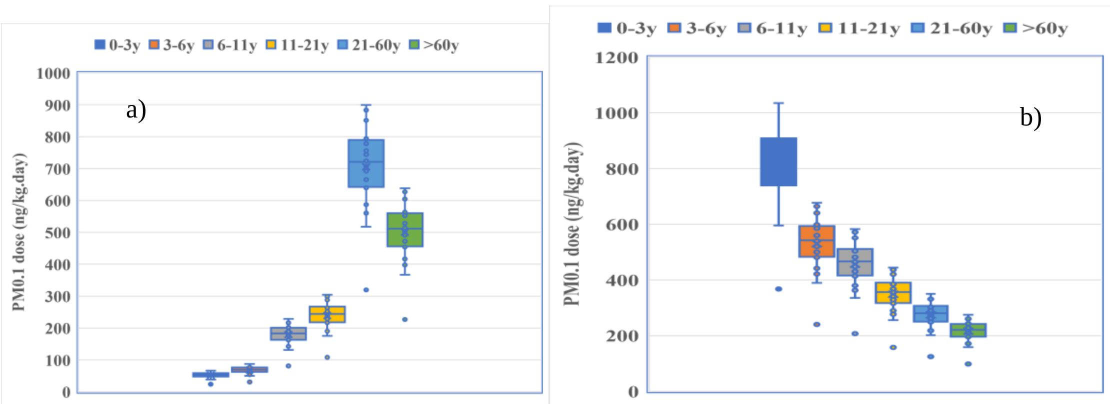

Figure 5. Respirable doses of $PM_{0.1}$: a) chronic effect; b) acute effect.

It is worth noting that, the use of the single-point value of input variables to calculate the daily dose for the population can rise the uncertainty in the outcomes. The application of Monte Carlo simulation was applied to avoid uncertainties in the calculation. In this part, some single point values of input variables varied randomly with 10000 trials for simulation using @Risk model version 8.0. The sensitive analysis also was conducted to define the influence of input variables on the outcomes based on the rank correlation coefficients [24]. Taking of 75th percentage, dose values range from 1384 to 5006 ng/kg.day for $PM_{2.5}$ and 239 to 900 ng/kg.day for $PM_{0.1}$ in case of acute effects; 335 to 4526 ng/kg.day for $PM_{2.5}$ and 58 to 782 ng/kg.day for $PM_{0.1}$, for chronic effects, respectively for corresponding age categories. The rank correlation coefficients of the input variable of PM concentration range from 0.85 to 0.94, meaning that the PM concentration influenced the most inhalation dose, while other factors are assumed to be ignored the influences.

4. CONCLUSIONS

In this study, $PM_{2.5}$ and $PM_{0.1}$ levels and their variation in December 2021 was presented simultaneously with simulating the acute and chronic effects on different categories of age in Hanoi, Viet Nam. The concentrations of $PM_{2.5}$ in December 2021 were in the range of 39 – 204 µg/m^3 with an average of 119 µg/m^3. The average level was approximately 2.4 times higher than the daily NAAQS. There was a prolong episode with the continuous 26 polluted days identified in this study.

There is negilible change on daytime and night-time $PM_{0.1}$ concentrations whereas those levels of $PM_{2.5}$ were remarkably different. $PM_{2.5}$ daytime concentrations were in the range of 39 – 205 µg/m^3 with an average of 106 µg/m^3. The level range of night-time was slightly wider, which varied from 39 to 230 µg/m^3 (average of 136 µg/m^3). The health implication of $PM_{2.5}$ and $PM_{0.1}$ in 26 days prolong episode provided suggestive evidence that the daily respirable doses for chronic effects rise with age categories, whereas those for acute effect decrease. The highest respirable doses were observed in children (0-3 years) for the acute effect, whilst those for chronic effects were found in the adults (above 21 years). The sensitive analysis found the PM concentration to be the most influencing factor in respiratory dose estimation. These findings could contribute to clarify the negative consequences of $PM_{2.5}$ and $PM_{0.1}$ on public health, thereby promoting to issue of effective management strategies to reduce health risks from air pollution. However, it is necessary to study more characteristics of PM to be able to calculate their impact on human health more fully. Our subsequent research will focus on particle composition and its health risks to fill up this gap.

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. Ly Bich Thuy: Conceptualization, Methodology, Data Visualization, Editing, Funding acquisition. Van Dieu Anh: Investigation, Editing, Nguyen Thi Thu Hien: Investigation, Editing. Nghiem Trung Dung: Review, Validation. Dao Duy Nam: Sample Monitoring Supervision. Nguyen Quoc Dat: Visualization.

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. 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 Ha Noi 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.
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) 2487-2497.
3. Cohen D. D., Crawford J., Stelcer E., and Bac V. T. - Long range transport of fine particle windblown soils and coal-fired power station emissions into Ha Noi between 2001 to 2008, Atmos. Environ **44** (2010) 3761-3769. https://doi.org/10.1016/j.atmosenv.2010.06.047.
4. Ngoc B. A. P., 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 Ha Noi during 2019 winter season, Atmos. Pollut. Res. **12** (2021) 101068.
5. Vo H .T. L., Anh V. D., Hien N. T. T., and Nghiem T. D. - Indoor and outdoor relationships of particles with different sizes in an apartment in Ha Noi: Mass concentration and respiratory dose, Vietnam J. Sci. Tech. **58** (2020) 736-746. https://doi.org/10.15625/2525-2518/58/6/15237.
6. 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, Vietnam Aerosol Air Qual. Res. **18** (2018) 1591-1605.
7. Stanaway J. D., Afshin A., and Gakidou E. - Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990-2017: A systematic analysis for the Global Burden of Disease Study 2017, Lancet **392** (2018) 1923-1994.
8. Dockery D. W. and Pope C. A. III - Acute respiratory effects of particulate air pollution, Annu Rev Public Health **15** (1994) 107-32.
9. Pope C. A. III. - What do epidemiologic findings tell us about the effects of environmental aerosol?, J. Aerosol Med. **13** (4) (2000) 335-54. DOI:10.1089/jam.2000.13.335.
10. Fang Y., Naik V., Horowitz L. W., and Mauzerall D. L. - Air pollution and associated human mortality: The role of air pollutant emissions, climate change and methane concentration increases from the preindustrial period to present, Atmos Chem Phys. **13** (94) (2013) 1377.
11. Meister K., Johansson C., and Forsberg B. - Estimated short-term effects of coarse particles on daily mortality in Stockholm, Sweden, Environ Health Perspect **120** (2012) 431-6. doi: 10.1289/ehp.1103995
12. Kim K. H., Kabir E., and Kabir S. - A review on the human health impact of airborne particulate matter, Env. Int. **74** (2015) 136-143.
13. Kloog I., Nordio F., Zanobetti A., Coull B. A., Koutrakis P. - Short term effects of particle exposure on hospital admissions in the Mid-Atlantic states: A population estimate, PloS. One **9** (2) (2014) e88578. https://doi.org/10.1371/journal.pone.0088578

14. Brauer M., Amann M., Burnett R. T., Cohen A., Dentener F., Ezzati M., Henderson S. B., Krzyzanowski M., Martin R. V., Dingenen R. V., Donkelaar A. V., and Thurston G. D. - Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution Environ, Sci. Technol. **46** (60) (2012) 652.
15. Guaita R., Pichiule M., Mate T., Linares C., and Diaz J. - Short-term impact of particulate matter ($PM_{2.5}$) on respiratory mortality in Madrid, Int. J. Environ. Health Res. **21** (74) (2011) 260.
16. 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., Kim Oanh N. T. - Chemical composition and potential sources of $PM_{2.5}$ in Ha Noi, Atmos. Environ **299** (2023) 119650. https://doi.org/10.1016/j.atmosenv.2023.119650
17. Vo, H. T. L., Anh, V. D, Hien, N. T. T., Nam D. D, Dung, N. T. and Thuy L. B - Concentrations of $PM_{0.1}$ and $PM_{2.5}$ at high polluting event days in Ha Noi and the effects of meteorological conditions Vietnam J. Sci. Tech. **61**(3) (2023) 471-479. doi:10.15625/2525-2518/16497.
18. Vietnamese Gorverment - Law No. 72/2020/QH14 on Environmental Protection, Vietnam National Assembly.
19. Nhung N. T. T., Schindler C., Dien T. M., Probst H. N., Perez L., and Künzli N. - Acute effects of ambient air pollution on lower respiratory infections in Ha Noi children: an eight-year time series study, Environ Int. **110** (2018) 139-48. 10.1016/j.envint.2017.10.024
20. Luong L. M. T., Phung D., Sly P. D., Morawska L., and Thai P. K. - The association between particulate air pollution and respiratory admissions among young children in Ha Noi, Viet Nam, Sci. Total Environ **578** (2017) 249-255. 10.1016/j.scitotenv.2016.08.012
21. Nhung N. T. T., Schindler C., Chau N. Q., Hanh P. T., Dien T. M., Thanh N. T. N., Hoang L. T., and Nino K. - Exposure to air pollution and risk of hospitalization for cardiovascular diseases amongst Vietnamese adults: Case-crossover study, Sci. Total Environ **703** (2020) 134637. 10.1016/j.scitotenv.2019.134637
22. Vu H. N. K., Ha Q. P., Nguyen D. H., Nguyen T. T. T., Nguyen T. T. H., Tran N. D., and Ho B. Q. - Poor air quality and its association with mortality in Ho Chi Minh city: Case study, Atmosphere **11** (7) (2020).
23. Vo H. T. L., Hien N. T. T., Nguyen A., Thai V., Minoru Y. - $PM_{2.5}$ bounded PAHs in the indoor and outdoor air of nursery schools in Ha Noi, Vietnam and health implication, Vietnam J. Sci. Technol. **58** (2020) 319-327.
24. Vo H. T. L., Minoru Y., Nghiem T. D., Yoko S., Van D. A., Hien N. T. T., Thuong N. T. - Indoor $PM_{0.1}$ and $PM_{2.5}$ in Hanoi: Chemical characterization, source identification, and health risk assessment, Atmos. Pollut. Res. **13** (2) (2022) 101324. https://doi.org/10.1016/j.apr.2022.101324.
25. Huyen T. T., Sekiguchi K., Thuy L. B, 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). https://doi.org/10.1016/j.scitotenv.2022.159869
26. US. Environment protection agency - Risk assessment guidance for superfund Volume I Human health evaluation manual, Washington, DC, USA, 2011.

27. Dat N. Q., Anh H. D., Thao N. T., Hung N. I., Ly B. T., Hien N. T. T., Dung N. T., and Van D. A. - Characteristics of haze episodes in Ha Noi, Viet Nam, Vietnam Environment Administration (1) (2021) 16-20 (In Vietnamese) http://tapchimoitruong.vn/nghien-cuu-23/mot-so-dac-diem-cua-cac-dot-haze-tai-ha-noi-26474.
28. 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. https://doi.org/10.1007/s40726-022-00220-z.
29. Ly B. T., Yukata M., Tuan V. V., Sekiguchi K., Thu T. N., Chau T. P., Dung N. T., Hung N. I., Yuta K., Hien N. T., and Nakayama T. - The effects of meteorological conditions and long-range transport on $PM_{2.5}$ levels in Ha Noi revealed from multi-site measurement using compact sensors and machine learning approach, J. Aerosol Sci. **152** (2021) 105716. https://doi.org/10.1016/j.jaerosci.2020.105716
30. Zhao T., Hongtieab S., Hata M., Furuuchi M., Dong S., Phairuang W., Ge H., Zhang T. - Ambient nanoparticles characterization by East and Southeast Asia nanoparticle monitoring network, In Proceedings of the 9th Asian Aerosol Conference, Kanazawa, Japan, 24-26 June 2015.
31. Mireille B., Zeina D., Frederic L., Anthony V., Fabrice C., Perrine M., Adam H., Pirouz S., Helene G. G., Dominique C. - Comparison between ultrafine and fine particulate matter collected in Lebanon: Chemical characterization, in vitro cytotoxic effects and metabolizing enzymes gene expression in human bronchial epithelial cells, Environ. Pollut **205** (2015) 250-260. https://doi.org/10.1016/j.envpol.2015.05.027
32. Pennanen A.S., Sillapaa M., Hillamo R. - 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
33. Lu S., Feng M., Yao Z., Jing A., Yufang Z., Wu M., Sheng G., Fu J., Yonemochi S., Zhang J., Wang Q., and Donaldson K. - Physicochemical characterization and cytotoxicity of ambient coarse, fine, and ultrafine particulate matters in Shanghai atmosphere, Atmos. Environ **45** (2011) 736-744. https://doi.org/10.1016/j.atmosenv.2010.09.020
34. Worradorn P., Muhammad A., Mitsuhiko H., Masami F. - Airborne Nanoparticles ($PM_{0.1}$) in Southeast Asian cities: A review, Sustainability **14** (16) (2022) 10074. https://doi.org/10.3390/su141610074
35. 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) 5063-5068. https://doi.org/10.1016/j.scitotenv.2011.08.049.
36. 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
37. U.S. EPA - Exposure Factors Handbook 2011 Edition (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.