The health risks of citizens due to $PM_{2.5}$ exposure in Ha Noi, Vietnam

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Abstract: A cancerous and non-cancerous risk assessment for PM2.5 exposure is essential, especially in developing children. PM2.5 was determined in concentrations in the Hanoi area both inside and outside the house according to 2019 data before the Covid epidemic, and the health impact assessment was performed for each subject according to the US. Research has also shown that the distribution of indoor PM2.5 concentration data in Hanoi has been determined according to the Weibull with a shape parameter is 8,695 and a scale parameter is 3,695. The average daily indoor PM2.5 concentration at four houses was higher than 20 µg/m3 higher than the warning of WHO guidelines. However, the average concentration on some days exceeded the threshold of Vietnam's standard. Meanwhile at K3, due to its location in the old town, the PM2.5 concentration is quite stable during the day and at a higher level than in other locations. Therefore, the effect of PM pollution in city houses is necessary for concern, monitoring and solving. This problem is not only present in Vietnam, this is the same in other countries such as some other research. So need to have guidelines when building new houses and inform citizens.

Keywords: $PM_{2.5}$, health risk, indoor pollution, ILCR.

1 Introduction

Approximately 9 out of 10 people in the world live in polluted air. With such a high percentage, this leads to a risk of exposure to the particle $PM_{2.5}$ found in the polluted air. Air pollution is a great matter of concern in Vietnam, especially particular matter (PM) pollution. The subjects most affected by PM pollution are the elderly, children, people with respiratory diseases, and people who work outdoors. The ultimate purpose of this paper is to understand the impact of air pollution and inform others on how to protect themselves.

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The first finding from the NIEHS-funded Children's Health Study at USC was that higher air pollution levels increase short-term respiratory infections, which lead to more school absences, affecting students' education. The second finding from the NIEHS-funded Children's Health Study at USC was that children who play several outdoor sports and live in high ozone communities are more likely to develop asthma. The third finding from the NIEHS-funded Children's Health Study at USC was that children with asthma who were exposed to high levels of air pollutants were more likely to develop bronchitis symptoms. These findings demonstrate that when children are exposed to air pollutants, they are more at risk for lung-related diseases. Data from 2019 demonstrates the significant amount of $PM_{2.5}$ in Ha Noi districts. All districts have levels of $PM_{2.5}$ that are over Vietnam's national regulation limit. The most central region has the most concentration of $PM_{2.5}$, suggesting that the region is the most densely populated and has a lot of transport interaction. However, these data percentages mainly concern groups aged 25 and above, not children

The issue of $PM_{2.5}$ levels has the potential to impact the health of children, therefore the study is an Assessment of the health risks of children due to $PM_{2.5}$ exposure in Ha Noi, Vietnam. The purpose of the study is to supplement knowledge about the dangerous level of $PM_{2.5}$ in indoor air in Hanoi. However, the study selected inhalation as the primary route of exposure.

The study object is $PM_{2.5}$, the Particulate Matter (PM) found in air pollutants, and the research scope is Ha Noi, the capital of Vietnam.

2 2. Research Method

2.1 Study location and direct measurement method

2.1.1 *Study locations*

Location of installation of sampling equipment in rooms in apartments, houses of Hanoi residents and some other locations. The direct $PM_{2.5}$ measurement devices are installed at 4 different locations. In addition, several locations where data validation and supporting data are provided are also shown, which are points marked S on the map.

The houses selected for sampling belong to the common house group in Hanoi. With the number of people who are often at home from 2-3 generations, including children and family members. The area of the rooms, the area of the house, the number of floors, and the number of people in the house do not have a big difference (except for K4 which is a new apartment). The houses are located in densely populated locations, representing small areas. Two types of houses are noticed: apartments and houses. For apartments is a difference between old and new-style apartments.

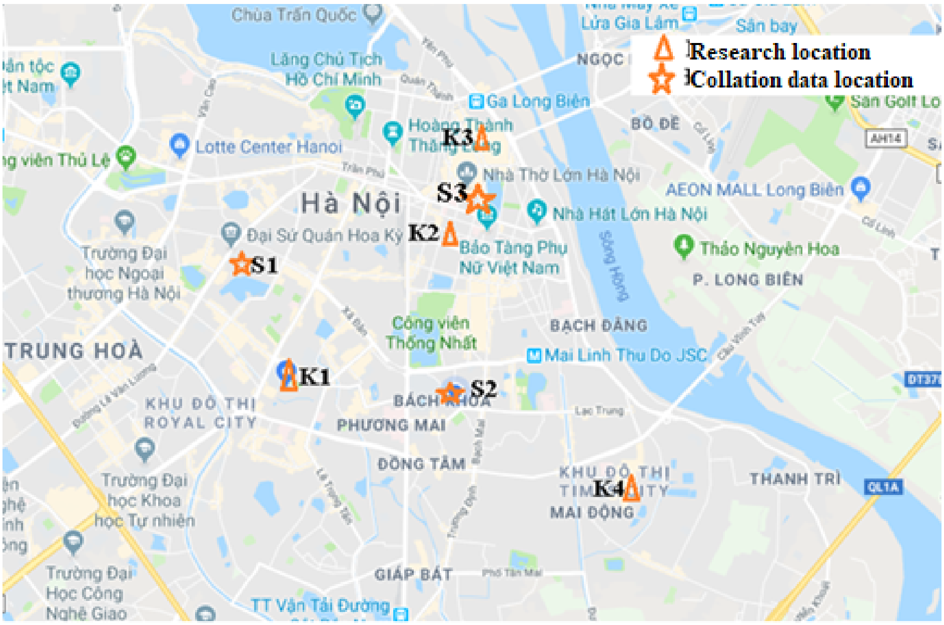

Figure 1. The study location is shown on Google Maps

2.1.2. PM measuring device

The monitoring of PM in the air can be done by taking samples or measuring by sensors, in this study, using compact, affordable sensor devices. These devices are evaluated for accuracy through fixed measuring stations. This method was chosen because the study of indoor air does not affect people's life, does not change the indoor air flow and is feasible in terms of resources. PM concentration and data are measured continuously. The data is collected differently with each different machine, the data displayed after 5s, 10s, and 60s needs to be aggregated and averaged out in 1 hour in 24 hours a day.

The PurpleAir and PATs+ use a fan to draw air through the laser, creating a scattering of laser light from airborne particles matters. These reflectors are used to count particles in six sizes between 0.3μm and 10μm in diameter. The second particle counting sensor measures the estimated total mass for $PM_{1.0}$, $PM_{2.5}$ and PM_{10} averaged by the PurpleAir Internet of Things (IoT) dashboard.

The device is Co-located with a Panasonic sensor in the laboratory, Panasonic sensor has been studied and calibrated according to the $PM_{2.5}$ monitoring device according to the US embassy's BAM method with an adjustment difference of 1.4.

Table 1. The results obtained during the correlation coefficient test and the resulting difference between the devices are shown by the equations and coefficients in the table below

Devices	PA2	P7808	P7806	P7807	P7253
PA1	y=0,9775x-0,2015 R^2=0,9977	y=1,1571x - 88,143 R^2=0,8649	y=1,156x-70,877 R^2=0,8927	y=0,9408-33,488 R^2=0,8734	y=1,3528x-106,79 R^2=0,9381
PA2		y=1,1432x-81,992 R^2=0,8608	y= 1.1588x-67.845 R^2 = 0.8718	y= 0.9788x - 35.809 R^2 = 0.8738	y= 1.3641x - 104.27 R^2 = 0.927

2.2 Data analysis and processing

The collected data is aggregated in the form of Excel data fields, including PM parameters along with factors of temperature and humidity, thereby converting the concentrations of PM_1, $PM_{2,5}$, and PM_{10} to the same condition. standard condition 25 ºC, 1 atm. The baseline statistics were determined and outliers were removed [Q1-3*IQR, Q3+3*IQR), IQR -interquartile range. From the results of the contaminant concentration calculate the health risk risks due to exposure and conduct an assessment and comparison with the results of other studies and the norm. The PM concentration status is compared with guidelines, regulations or standards.

2.3 Study location and direct measurement method

The health risk assessment for $PM_{2.5}$ follows the four basic steps of the US EPA, 2009. The process is carried out through research, data collection and using the calculation formulas presented below. The parameters provided for the calculation process are collected from the actual survey, with the other non-zero parameters being studied and synthesized from different sources.

Table 2. Parameters for the calculation of daily exposure

Value	Units	Case 1: Children	Case 2: Adults	Case 3: Elderly	Source
IR_A	m^3/d	14,5	15,8	15,8	Popstoolkit, US EPA 2004
AF_{Inh}		1	1	1	Popstoolkit, US EPA 2004
D_{Hours}	hour/day	21	14	14	This research
D_{Days}	day/week	7	7	7	Popstoolkit, US EPA 2004
D_{Weeks}	week/year	52	52	52	Popstoolkit, US EPA 2004
D_{Years}	year	70	70	70	Popstoolkit, US EPA 2004
BW	kg	28	52	58	This research
LE	year	70	70	70	World Bank 2015
TDI		0,85			

The risk assessment method follows the four steps of the US EPA toolkits including Hazard identification of carcinogenic substances, and non-carcinogenic substances; Assessment of exposure through calculating the dose of exposure through the routes, research to choose the airway as the path of $PM_{2.5}$ in the air in contact with the respiratory organs;

Toxicological assessment through the determination of SF cancer coefficient and determination of acceptable intakes per day TDI; Assessment of risk characteristics through Incremental Lifetime Cancer Risk - ILCR and hazard quotient - HQ.

$$DI = \frac{C_{air} \cdot IRA \cdot Dhour \cdot Dday \cdot Dweeks \cdot Dyears}{24 \cdot BW \cdot 365 \cdot LE}$$

The meaning of each value:

DI: the amount of $PM_{2.5}$ absorbed into the body per day through inhalation (mg/kg. day $^{-1}$).

Cair: the contaminant exposure concentration (μg/m^3).

IRA: Respiratory Rate (m^3/day).

Dhour: exposure time in hours (hours/day).

Ddays: day of the week where the exposure occurred (0-7).

Dweeks: Week of exposure in 1 year (0-52).

Dyears: Years of exposure (do not use non-carcinogenic* pollutants).

BW: Subject's average weight.

LE: Desired age (years) (do not use in case of non-carcinogenic* contaminant).

*having the potential to cause cancer.

$$SF = \frac{UR}{(BW)(IRA)}$$

SF: Cancer coefficient (mg/kg-day-1).

UR: Inhalation risk factor (μg/m^3).

BW: Subject's average weight.

The assessment of toxicity for carcinogens is determined by the carcinogenic factor (Slope factor (SF)) and corresponds to non-carcinogenic substances as the tolerable daily intake (Tolerable Daily Intake – TDI).

ILCR= $Dose_{Inhalation}$ x $SPF_{Inhalation}$

ILCR: Factor that calculates the total increased risk of cancer over life.

Dose: Mean lifetime exposure dose (mg/kg-day).

Non-Threshold Contaminants are toxins that affect nearly any level of exposure, meaning that any level of exposure carries some degree of risk. Most carcinogens are generally considered to be non-threshold pollutants. The risks of non-threshold pollutants were assessed using the US Environmental Protection Agency (ILCR)'s Incremental Lifetime Cancer Risk (ILCR) model).

$$HQ = \frac{Dose_{Inhalation}}{TDI}$$

HQ: Risk calculation coefficient (>1: Existence of risks to human health).

TDI: Tolerable daily intake (mg/kg-day)

Threshold pollutants are toxic substances that have an effect when a certain exposure concentration is exceeded. Most pollutants are threshold pollutants. The maximum allowable exposure concentration, known as the exposure limit, is determined based on toxicity tests. Exposure limits for threshold pollutants are usually expressed as tolerable intakes per day (TDI). The degree of risk for non-carcinogenic substances is assessed through the hazard quotient (Hazard Quotients -HQ).

3 Results

3.1 PM concentration data results

3.1.1 Probability density distribution of PM concentration

The observation time at K1, K2, and K4 is short compared to the total time of the study, and the amount of data collected is much different from point K3. In determining the probability distribution function of $PM_{2.5}$ concentration, the data at point K3 using PurpleAirII (PA1) device is suitable for determining the PM concentration probability density distribution law.

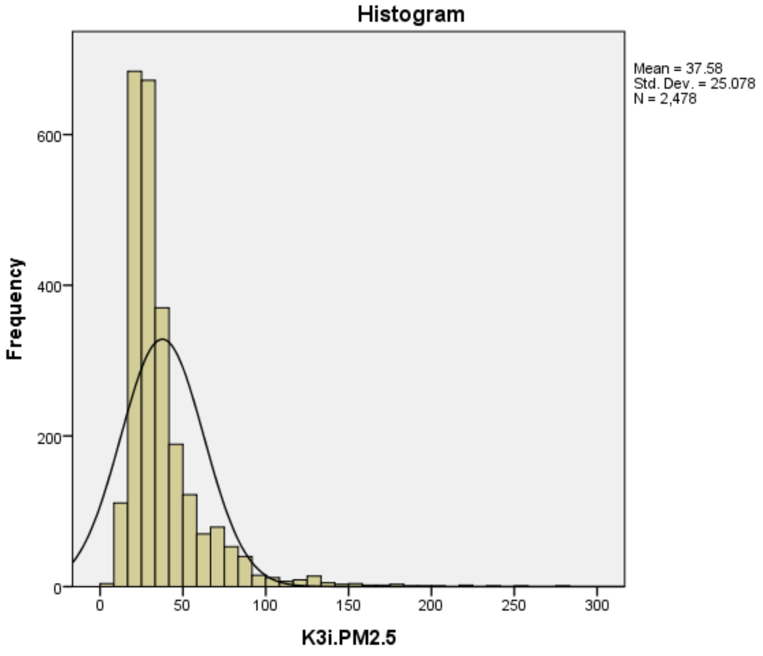

Figure 2. The graph shows the distribution of $PM_{2.5}$ concentration is not according to the normal distribution.

With data of indoor $PM_{2.5}$ concentration at K3 determined, it shows that the probability density distribution function of PM concentration is not normally distributed. The peak distribution pattern is skewed to the left, decreasing to the right. The distribution rule found to be suitable is the Weibull function.

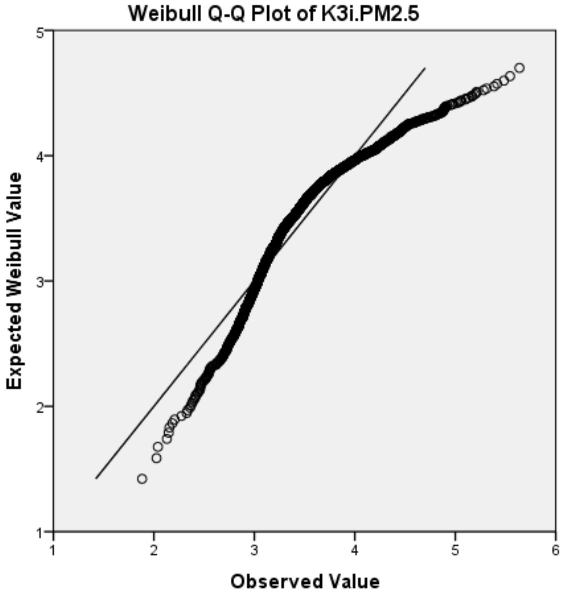

Figure 3. Calculation test graph with fraction function Weibull

However, knowing the shape of the data distribution is only the first step to better understanding the characteristics of the dataset. The more important objective is to determine the distribution density function, cumulative frequency distribution function, and threshold frequency of the quantities. The probability distribution function is called the Probability Density Function. Statistical data with 95% confidence. The data at K3 were checked for fit and estimated the scale and shape parameters of the Weibull distribution for the dataset.

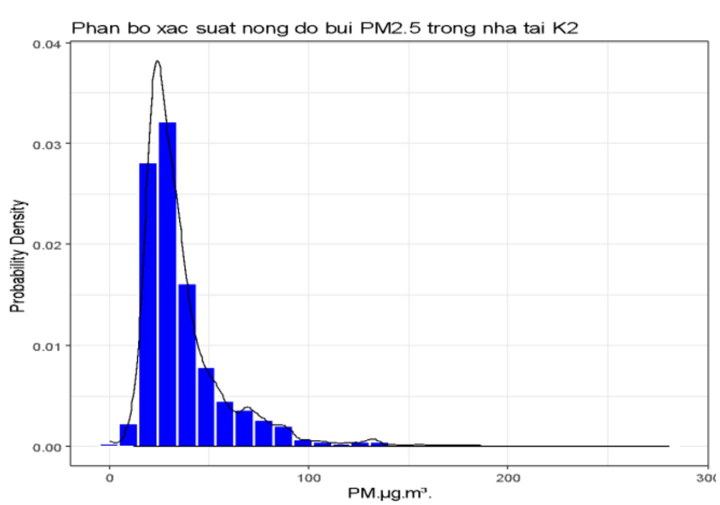

Figure 4. Graph showing probability distribution of PM concentration at K3.

Table 3. Estimated Distribution Parameters

		K3i.$PM_{2.5}$
Weibull Distribution	Scale	3,686
	Shape	8,695

3.1.2 Status of PM concentration in indoor air

The result of $PM_{2.5}$ concentration collected at site K3 had the highest peak of 280.9 μg/m^3 at 11 pm on January 19, 2019, at the same time, concentration Outside the house reached the threshold of 180 μg/m^3, on January 19, 2019, is the 7th and 14th day of the 12th lunar month, as shown in the results in the part of $PM_{2.5}$ concentration by day of the week, at the end of the week, there is a difference in $PM_{2.5}$ concentration. At the same time, according to the people's custom of worshipping the full moon, burning incense and burning votive papers is common, usually on the evening of the 14th and 15th of the lunar calendar. According to data from the US Embassy, 7 Lang Ha (S1), the result obtained at 11 pm on January 19, 2019, was 146 μg/m^3, and the concentration of $PM_{2.5}$ was in the range of 118-152 μg/m^3. from 6pm on the 14th to 5th on the 15th of December. While at the same time, points K2, K3, and K4 are all high points of the day.

According to a study on air quality at childcare centres in Malaysia, Raihan Khamal (2019), the concentration of $PM_{2.5}$ pollutants reached the threshold of 174 μg/m^3 in the bedroom, with $PM_{2.5}$ concentrations outside. the highest weather to 430 μg/m^3 hourly average during the study period.

According to another study in Bangkok, Thailand, the $PM_{2.5}$ is mainly $PM_{2.5}$, higher in buildings located in urban areas or near highways. At a preschool, $PM_{2.5}$ concentrations were collected at a high level of 112.62 ± 32.82 μg/m^3 in urban areas. From research results from Southeast Asian countries and research results, it can be concluded that indoor PM pollution occurs in many different spaces at a high level, exceeding the recommendations of the World Health Organization. world economy for outdoor air 25 μg/m^3 many times. Measures to improve indoor air quality and further $PM_{2.5}$ concentration monitoring are required for a specific assessment.

Table 4. Summary of $PM_{2.5}$ monitoring results

		K1	K2	K3	K4
Average hourly indoor $PM_{2.5}$ concentration	Min,	4,8	5,3	7,8	3,7
	1st Qu,	5,0	8,1	23,1	10,8
	Median	10,3	17,7	30,2	17,0
	Mean	23,9	24,6	37,47	22,3
	3rd Qu,	32,3	36,7	42,1	29,2
	Max,	155,4	93,2	280,9	85,0
Average daily indoor $PM_{2.5}$ concentration	Min,	5,1	3,3	17,0	8,1
	1st Qu,	7,2	7,9	26,8	12,0
	Median	15,0	22,8	30,6	16,8
	Mean	23,8	23,9	38,4	21,1
	3rd Qu,	38,9	35,7	42,6	30,9
	Max,	81,7	53,8	116,0	47,4
Average hourly $PM_{2.5}$ concentration outside the house	Min,			0,0	4,6
	1st Qu,			31,6	16,7
	Median			42,5	28,8
	Mean			50,2	34,5
	3rd Qu,			58,1	45,3
	Max,			189,3	127,2

During the monitoring period at K3, from December 26, 2018, to April 9, 2019, 17 out of 105 days of monitoring $PM_{2.5}$ levels in the K3 house exceeded the permissible PM concentration threshold of the MONRE. However, in Vietnam, there is no regulation on indoor $PM_{2.5}$ concentration. Compared to the annual average allowable PM concentration outdoors, only 7 days are within the limit. Compared with US EPA regulations, all measured days at K3 are above the safe level.

3.1.3 Evolution of PM concentration over time

The hourly average PM concentration is aggregated and analyzed to vary 24 hours a day. The common point of all 5 locations is that the PM concentration at noon is higher than at other hours, point K3, Hang Chieu also has a peak in the afternoon time. The concentration of $PM_{2.5}$ may be high during the daytime when there is a lot of human activity. Location K3 is located in the old town area, and nightlife activities are more than in other points.

At K3, the hourly average concentration of the day is stable at a high level, and the difference between hours is smaller than at other points. $PM_{2.5}$ concentration tends to be higher at noon and night from 11:00 to 13:00, and 23:00 to 2:00, the difference is small, maybe one of the reasons for the influence is that Hang Chieu is located in the old town area, activities are Vibrant day and night.

At K1, K2, and K4, $PM_{2.5}$ concentration is higher during the day, especially at noon, and lower at 3 am-5 am. It can be explained by human activities during the day that greatly affects the PM concentration at these points.

Indoor $PM_{2.5}$ concentration in K3 is always the highest on all days of the week, from Monday to Sunday, $PM_{2.5}$ concentration is highest at K3 at 59.9 µg/m^3; 61.1 µg/m^3; 82.2 µg/m^3; 96.7 µg/m^3; 116.0 µg/m^3; 100.0 µg/m^3; 108.5 µg/m^3. On Fridays, Saturdays, and Sundays, the pedestrian street in the Old Quarter area takes place, Hang Chieu Street is not blocked, so the traffic here is also more crowded than usual, which can be a cause of increased $PM_{2.5}$ concentration.

The lowest $PM_{2.5}$ concentration in the week from 4-7 μg/m^3 was obtained indoors from monitoring point K1. This is a point located deep in a residential area, more than 500m from the main traffic axes. The road is a small residential road. Although the area is densely populated, the operation is mainly closed, the sources are mainly local. The data obtained from day K1 had the highest concentration of 7 weeks, with a concentration of 32.1 μg/m^3, this data can be explained in the survey due to the activity on Saturday afternoon when the members were all at home. house and clean the house for several weeks during the monitoring period.

The highest indoor $PM_{2.5}$ concentration at points K2, and K4 reached 53.8 μg/m^3 on Friday and 47.4 μg/m^3 on Monday, respectively. These two points are influenced by construction activities and complex means of transport. K2 is affected by the honeycomb charcoal stoves that people use within a radius of 100m.

In general, the evolution of $PM_{2.5}$ concentration during the week of all four survey locations of indoor $PM_{2.5}$ concentration is not the same. At K1, there is not much difference during the week and weekend, the daily indoor $PM_{2.5}$ concentration here ranges from 3.7 to 32.1 μg/m^3. At K4, indoor $PM_{2.5}$ concentration was higher on weekdays, while at K2 and K3, $PM_{2.5}$ was both slightly higher at weekends and the whole week average was higher than the other two points. The average indoor $PM_{2.5}$ concentration for the whole week of 4 monitoring points from low to high is K1: 14.5 μg/m^3, K4: 21.1 μg/m^3, and K2: 23.9 μg/m^3 respectively. , K4: 37.5 μg/m^3.

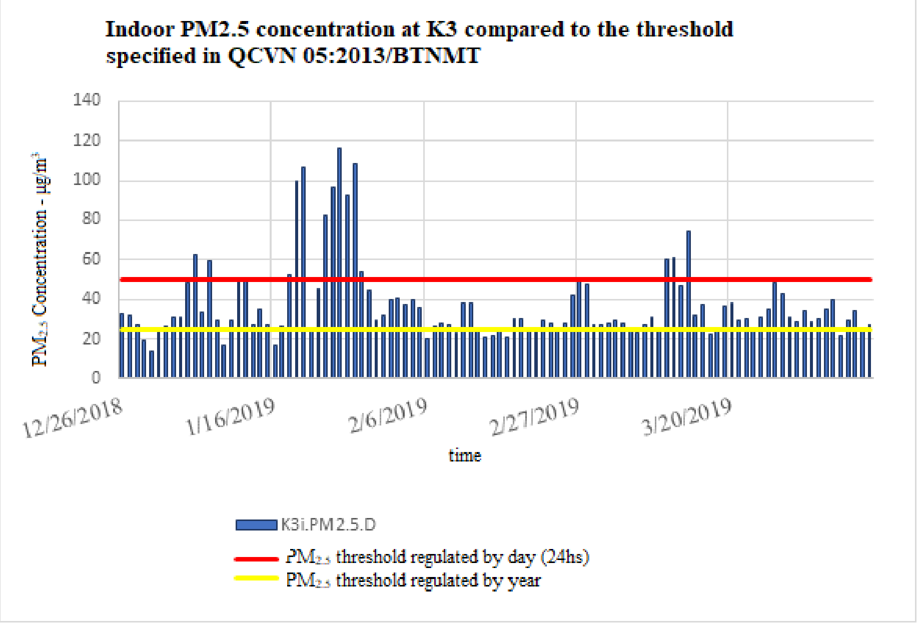

Figure 5. $PM_{2.5}$ concentration at K3

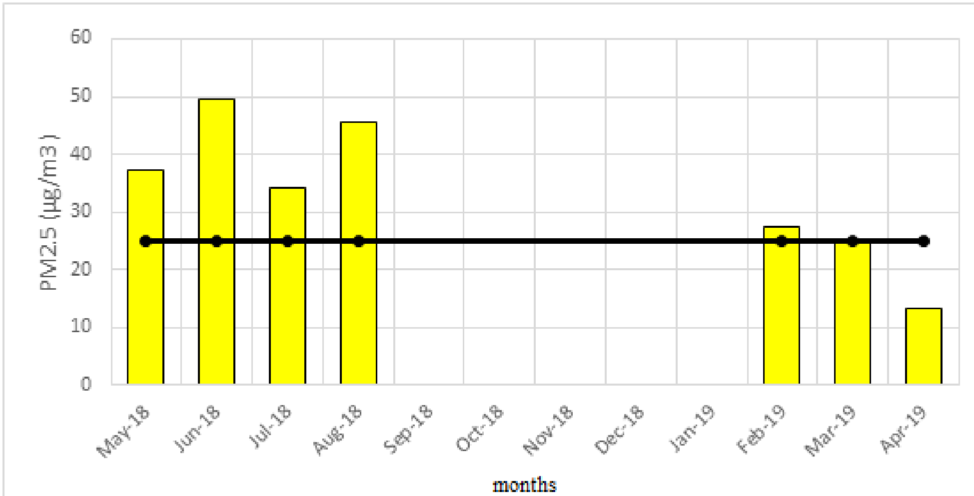

Figure 6. $PM_{2.5}$ concentration by month at K1

3.2 Health Effects of $PM_{2.5}$ in the indoor environment

$PM_{2.5}$ can cause acute and chronic effects. Within the framework of this study, cancerous and non-cancerous risk assessments for $PM_{2.5}$ exposure were selected for assessment.

The three main routes of $PM_{2.5}$ exposure are dermal exposure, ingestion, and inhalation. However, respiratory selection studies are the primary route of exposure. The case selected for the study is children (5-11 years old), and adults (>=20 years old). Three specific subjects were selected for the study, a 7-year-old child, weighing 28kg and a 37-year-old mother, weighing 52kg, most of the days were at home from 5 pm to 7 am. The third study subject is a 69-year-old woman, weighing 58kg, and staying at home 21 hours a day. The location to assess health risks when exposed to $PM_{2.5}$ is point K3, No. 60 Hang Chieu, Hoan Kiem, Hanoi. For cancer risk: According to the calculation results of all 3 cases in the average 24h period, with indoor and outdoor $PM_{2.5}$ concentrations at K3 the cancer risk is in the range of 10^{-4} to 10^{-6}, medium risk. Study Case 3, who spent 21 hours a day indoors, and Case 2, 14 hours a day, both had moderate cancer risk results both indoors and outdoors. Study Case 1 had a real-time indoors of 14 hours, with an average cancer risk of $2.14.10^{-5}$ but higher than Case 2: $6,21.10^{-6}$ and Case 3: $6,21.10^{-6.}$

As for the non-carcinogenic risk, all three study subjects had a high level of risk as recommended by the US EPA. Notably, case 1 (child) is the subject with the largest non-carcinogenic risk coefficient (HQ) and has a high level of risk. Young children are the most sensitive age group, this group has immature immune and respiratory systems, so the health risks are also the greatest. Therefore, controlling indoor air pollution quality for families with young children is extremely necessary.

When calculating indoor and outdoor risks with the assumption that the indoor $PM_{2.5}$ exposure concentration is measured from the actual and the PM concentration from the US embassy data, the results show that the cancer risk coefficient (average in 24h) for all 3 subjects is average. However, the calculated non-cancer risk was high for all three subjects.

The results also show that the assessment of health effects in all three subjects when exposed to $PM_{2.5}$ indoors is larger than outdoors. The calculated results in this study for adults are similar to the study of Hyungkeun Kim et al. in 2018. Which, the authors measured $PM_{2.5}$ concentration and assessed the risk. health risks of $PM_{2.5}$ from cooking in apartment kitchens and living rooms. This study was conducted in an apartment house in the South of Korea, measuring $PM_{2.5}$ in the kitchen and living room, with ventilation by ventilators, hoods and windows. Parameters used for calculation: mean respiratory factor for both female and adult males is 14.25 $\mu g/m^3$, mean weight for adult males and female is 62.8kg, risk calculation method according to US EPA guidelines. The cancer risk outcome is $4.18.10^{-5}$ – $4.88.10^{-5}$ at the US threshold average. Thus, when exposed to PM, risks always exist, however, the new study stops at the initial step of determining the risks due to $PM_{2.5}$ exposure, to have a detailed and complete assessment, it is necessary to have additional research.

Table 5. Risk calculation results

Case		Time	C	DI	LDAD	SF	TDI	ILCR	HQ
			$\mu g/m^3$	mg/kg-day	(mg/kg-day)	$(mg/kg\text{-}day)^{-1}$	(mg/kg-day)		
3	Inside	24h	44,45	0,05	0,50	0,00021	0,85	$9,71.10^{-6}$	0,59
	Outside	24h	39,16	0,04	0,44	0,00021	0,85	$8,55.10^{-6}$	0,52
	Inside	10:00-5:00	39,20	0,04	0,39	0,00021	0,85	$7,49.10^{-6}$	0,46
2	Inside	24h	44,45	0,05	0,56	0,00023	0,85	$1,21.10^{-5}$	0,66
	Outside	24h	39,16	0,05	0,49	0,00023	0,85	$1,06.10^{-5}$	0,58
	Inside	17:00-6:00	39,17	0,03	0,29	0,00023	0,85	$6,21.10^{-6}$	0,34
1	Inside	24h	44,45	0,09	0,96	0,00047	0,85	$4,17.10^{-5}$	1,13
	Outside	24 hrs	39,16	0,08	0,84	0,00047	0,85	$3,67.10^{-5}$	0,99
	Inside	5 pm to 7 am	39,17	0,05	0,49	0,00047	0,85	$2,14.10^{-5}$	0,58

Table 6. Level of Risk of Exposure to Cancer

Risk of exposure to cancer	
ILCR	Level
$ILCR<10^{-6}$	Low
$ILCR=10^{-6}\text{-}10^{-4}$	Average
$ILCR>10^{-4}$	High

Table 7. Level of Risk of Exposure to other diseases

Risk of exposure to other diseases	
HQ	Level
HQ<0,2	Low/None
HQ > 0,2	High

The result table compiles the risk calculation results, with the first table being the overall comprehensive results and the two other tables detailing rates of ICLR and HQ. According to the first data table, children had the highest HQ at 0.99 and ILCR at $4{,}17.10^{-5}$. Even more surprising is that the highest HQ was recorded when the children were inside, whereas the ILCR was outside. DI rates for all subjects hover around 0.03 to 0.09, with children inside having the highest amount of $PM_{2.5}$ absorbed into the body per day through inhalation (mg/kg. day^{-1}). Children inside also had the highest LDAD at 0.96. This demonstrates that even when the children are inside, they are still most likely to be exposed to $PM_{2.5}$ which ultimately in the long term can lead to diseases like cancer.

4 Conclusion

- Probability density distribution of $PM_{2.5}$ concentration: The probability density distribution law of $PM_{2.5}$ concentration data in houses in Hanoi has been determined according to the Weibull distribution. Which, with a monitoring point of 60 Hang Chieu, the shape parameter is 8,695 and the scale parameter is 3,695.
- PM Pollution level: The average daily concentration of indoor $PM_{2.5}$ in the whole batch at K1, K2, K3 and K4 was 23.8 μg/m^3 respectively; 23.9 μg/m^3; 38.4 μg/m^3 and 21.1 μg/m^3. However, there were many days when the average concentration exceeded the threshold of QCVN05:2013/BTNMT (50 μg/m^3), in which, at point K3, 17/105 days exceeded the threshold. The study measured the outdoor air $PM_{2.5}$ concentration at points K3 and K4. The average hourly concentration during the whole episode was 50.2 μg/m^3 and 34.5 μg/m^3 respectively; with peak values of 189.3 μg/m^3 and 127.2 μg/m^3 respectively.
- Evolution of PM concentration over time: The time-of-day evolution of indoor PM concentration is quite complex, depending heavily on the specific activities both inside and outside the house being monitored. At points K1, K2 and K4, $PM_{2.5}$ concentration during the day are higher than at night. Meanwhile at K3, due to its location in the old town, the $PM_{2.5}$ concentration is quite stable during the day and at a higher level than in other locations.
- The evolution of indoor PM concentration between days of the week is quite complicated, depending on the area of the house being monitored. In general, houses in Hoan Kiem district (K2 and K3) have higher PM concentration on weekends and lower working days. For the remaining points (K1 and K4), the basic trend is the opposite. At the point with long-term monitoring data (K1), indoor PM concentration is higher in the summer months and lower in late winter and early spring. At the same monitoring point, there is a good correlation between indoor and outdoor $PM_{2.5}$ concentrations. Specifically, at K3 and K4, the correlation coefficient R is 0.91 and 0.78, respectively. This shows that indoor PM is largely dominated by outdoor, indoor PM concentration is higher because there is a source generated indoors.
- Evolution of PM concentration by space: The concentration of PM_1, $PM_{2.5}$, and PM_{10} at each monitoring point has a good correlation. That said, they may be governed by the same key sources. Both indoor and outdoor $PM_{2.5}$ has a certain negative correlation with temperature.
- Assessment of health risks from $PM_{2.5}$ exposure

Cancer risk: All three study subjects had an average risk, a higher risk for children than adults. The risk of cancer of the three subjects was $2.14.10^{-5}$, respectively; $6.21.10^{-6}$ and

6.21.10^{-6}. This level of risk is recommended by the US. EPA needs further research and social attention.

Non-cancerous risk: All three subjects had a high level of risk. Particularly for children, the risk level is nearly three times higher than the threshold. Controlling indoor air pollution is essential for families with young children.

Acknowledgements

A comprehensive health assessment of $PM_{2.5}$ is based on pollutant composition and with a larger sample size and a combination of health assessment by medical professionals. This study is a case of PM influence on a specific location, typically in the central area of Hanoi. The specific direction of many indoor spaces taking into account climatic and meteorological conditions should be considered in the future.

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Anh Le promoted the process of finalizing the manuscript, organizing the data and writing the article.

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