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RISK ASSESSMENT FOR PM 10 AND PM 2.5 IN HANOI, VIETNAM: AN ECOLOGICAL STUDY

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ABSTRACT

Particular matter is one of the main pollutants in air pollution, especially more in emerging and developing cities. In the midst of urban development, Hanoi City experienced a rapid increase in vehicles and traffic in recent years, which is believed to be the cause of particular matter concentration and air pollution. Long Bien, an Eastern district in Hanoi, is subject to increasing population and traffic, yet the lack of sufficient risk assessment of particular matter situation on health and environment is evident. This paper aims to assess current situation of PM2.5 and PM10 pollution in Long Bien District, Hanoi City, thus calculate health and ecological environment risk due to particular matter pollution. The data indicated although Long Bien area saw a decrease in concentration of pollutants, however the data still exceeded the permitted standard. PM10 and PM2.5's concentration values were particularly high in October to March, and lower in April and September, which is compatible and explainable with wind and climate season in Northern part of Vietnam. PM2.5/PM10 ratio fluctuated over the years, while highest ratio was seen in 2017 (0.74). In contrary to seasonal changes, PM2.5/PM10 ratio was highest in summer time (May - 0.76) and lowest in winter time (January - 0.67). From comparison to two cities in the region, PM10, PM2.5's concentration and PM2.5/PM10 ratio remained in average position, all figures were lower than observed in Beijing but higher than observed in Singapore. While ecological environmental in Long Bien remained in high risk throughout the observed period, health risk assessment showed population health was also at risk of morbidity and mortality due to exposure to PM10 and PM2.5 with relative risk higher than 1. The trend of PM2.5 and PM10 concentration exceeding the limits in national standard throughout the years indicated that air pollution control in Long Bien area in particular and in Hanoi city in general remains an environmental health issue. Further high risk in public health and ecological health is signal for comprehensive intervention and policies from stakeholders, while emphasizing the need for further research of particular matter in Vietnam.

KEY WORDS : Particular matter, PM10, PM2.5, Health risk assessment, Hanoi, Vietnam.

INTRODUCTION

Particulate Matter (PM) is the term for a mixture of solid particles and liquid droplets found in the air. These particles come in many sizes and shapes and can be made up of hundreds of different chemicals. The most commons in particular pollution are PM10 and PM2.5. PM can be found in air with extremely small dimensions. PM10 is inhalable particles, with diameters that are generally 10 micrometers and smaller. PM2.5 dust is very small and light, it exists suspended in the air much longer than other dust particles. PM2.5 dust is especially dangerous for people with heart and lung disease, older people and children. As healthy people ingest PM2.5, these dust can easily pass through respiratory system, penetrate the deepest parts of the lungs as far as the air exchange areas through diffusion. Inhalation of PM2.5 and PM10 can lead to cough, chest tightness, difficulty breathing, irritation of the eyes, nose, throat, asthma, bronchitis and other respiratory problems . PM dust is usually generated during the burning of organic and inorganic materials in transport, industrial and domestic activities.

Hanoi is one of the cities with the largest traffic density in Vietnam. Within the first 8 months of 2018, Hanoi Police Department reported having provided registration for more than 218,000 vehicles, of which more than 38,000 cars, 170 thousand motorcycles (Gia, 2019). Due to the increasing amount of vehicles from the beginning of 2018 until now, on average each month, Hanoi has more than 27 thousand cars, motorbikes and electric bicycles granted registered number (Gia, 2019). It is said that the rapid increase in means of transport is causing an increase in PM dust concentration, thus one of the main cause of air pollution in Hanoi (Phung *et al.,* 2016). Indeed, many research showed associations between PM concentration and increased risk of hospitalizations and rates of morbidity and mortality in high populated dense traffic cities in Vietnam Hanoi), Hai Phong (Vu *et al.,* 2013). Hens, Application of GIS and modelling in health risk assessment for urban road mobility, 2013), Ho Chi Minh City (Phung *et al.,* 2016). All suggested a high correlation between traffic-related PM and health burden.

Long Bien District, located in the East of Hanoi, is an important transport gateway connecting the capital city with nearby provinces such as Hung Yen, Hai Duong, Hai Phong, Bac Ninh. The district is experiencing rapid urbanization and increasing population in recent years.

The paper aims to investigate the situation of PM2.5 and PM10 pollutants in Long Bien District, from there assess potential health impacts for local residents in this area.

METHODS

Research area

Authors conducted research at automatic air monitoring station located at 556 Nguyen Van Cu Street, Gia Thuy, Long Bien District, Hanoi. This monitoring station is located near the traffic road.

Collection of data

PM10, PM2.5 data were collected using Grimm measuring device 180 (PM-dust) (from 2013 - 2017). Concentrations of PM10, PM2.5, continuous measurement (5 minutes/time), averaged hours over the entire time data was collected. Data rate is 80% (after removing abnormal values, data during machine or device calibration is not working). Missing data and abnormal data are not included in statistical calculations.

Data analysis

PM10, PM2.5 data was collected and analyzed by Microsoft Office Excel. All data would be descriptively described, then compared with data set from two cities: Beijing, China and Singapore, Singapore. This comparison was justified by: (1) the availability of same period data set in Beijing, China and Singapore, Singapore from 2013 to 2017; and (2) the closeness in geographical region, climate conditions, metropolitan characteristic and size-wise between three cities. PM concentration in Beijing, China from 2013 to 2017 was collected from UN Environment's report of 20 year's air quality monitor in Beijing (Environment, 2019). PM concentration in Singapore from 2013 to 2017 was collected from Annual Air Pollution level of PM_{10} and PM2.5 in Singapore from 2007 to 2018 Report by Statistica Research Department (Annual Air Pollution level of PM10 and PM2.5 in Singapore from 2007 to 2018, 2020).

Methods of assessing ecological environmental risks through the determination of quotient of risk quotient numbers

The method of calculating risk quotient (RQ) is applied to assess the semi-quantitative risk based on the physicochemical characteristics of pollutants exhausted from waste sources in the environment to assess potential risks of a certain substance to complex environment or pollutants to the ecological environment. The method includes calculation and forecasting the level of environmental risk at different levels. RQ is essentially the ratio between the pollutant concentration and the limit value specified in the standard. RQ is calculated by the formula (1):

$$RQ_i = MEC_i/C \quad .. (1)$$

In which:

MEC_i: pollutant concentration

C: Limited value in environmental quality standards.

To assess environmental risks by RQ method, we used multiple levels based on the calculated RQ's value range, thereby drawing conclusion about risks to the area environment. Typically, environmental risks are categorized into four different levels from very low risk to very high risk (Table 1) (Hong Tran Thi, 2008).

Table 1. Levels of environmental risk assessment

Level of risk	Value of R Q	Hazard
1	< 0.01	Very low risk
2	0.01 - 0.1	Low risk
3	0.1 – 1	Medium risk
4	≥ 1	High risk

Methods for assessing health risks for PM10 and PM2.5

Risk of exposure to health risks for PM10

Attributable health risk among population exposed to PM10 is calculated based on the relative risk index (RR). The relative risk (RR) for all-cause mortality associated with short-term exposure to PM10 is calculated by formula (2):

$$RR = \exp[\beta(X-X_0)] \quad (2)$$

In which:

X: average annual concentration of PM10 (μg/m^3)

X_0: limited concentration of PM10 (μg/m^3). As recommended by the World Health Organization, the limit of PM10 for health is 10 (μg/m^3) (Organization, 2014)

β: coefficient of risk function (with confidence of about 95%, then β is in range: 0.0006–0.0010, suggested value calculated: 0.0008) (Hong Tran Thi, 2008).

Attributable mortality rate due to PM10 dust-related diseases is determined by the formula (3):

$$ER = [(RR-1)/RR]100 \quad .. (3)$$

Risk of health risks related to exposure to PM2.5

Attributable health risk among population exposed to PM2.5 is calculated based on the relative risk index (RR). The relative risk index (RR) determining lung cancer risk for people over 30 years old associated with long-term exposure to PM2.5 is calculated by the formula (4):

$$RR = [(X+1)/(X_0+1)]^b \quad .. (4)$$

In which:

X: average annual concentration of PM2.5 (μg/m^3)

X_0: limited concentration of PM2.5 (μg/m^3). As recommended by the World Health Organization, the limited concentration of PM2.5 is 3 (μg/m^3) (Organization, 2014).

β : coefficient of risk function (with confidence of about 95%, then β is between: 0.08563–0.37873, calculated value calculated: 0.23218) (Hong Tran Thi, 2008).

Attributable morbidity rate due to PM dust-related diseases 2.5 is determined as the formula (5):

$$ER = [(RR-1)/RR]100 \quad (5)$$

RESULTS

Concentration of PM10 and PM2.5 from 2013 to 2017

PM10 dust concentration in Long Bien in the years 2013-2017 (Figure 1) tends to decrease over time, ranging from 83.3 to 48.2 (μg/m^3). Except in 2017, the concentration met the permitted standard of 50 (μg/m^3), PM10 dust concentration in before years was higher than the permitted standard by Vietnam Ministry of Natural Resources and Environment (QCVN 05:2013/BTNMT).

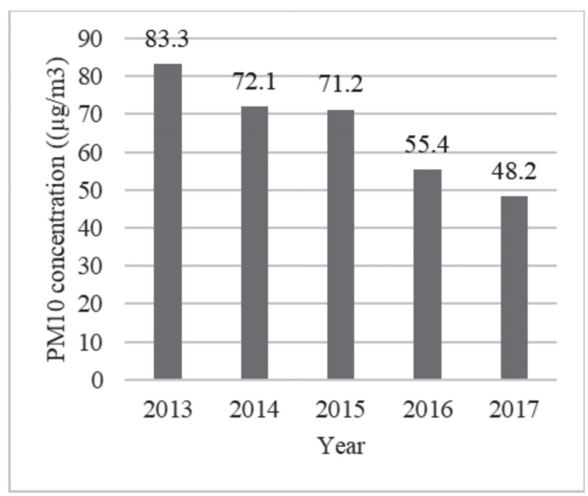

Fig. 1. PM10 concentration in 2013-2017 in Long Bien, Hanoi

The declination of PM10's concentration in Hanoi was homogeneous to Beijing and Singapore in the same period (Figure 2). This can be interpreted as air quality has been an emerging topic in many countries, especially in metropolitans in Southeast Asia where air pollution has been adversely affected population's wellness. With stronger initiatives in the above mentioned countries (Hesketh *et al.*, 2017) (Quarmby and Santos, 2019) (China (Zhao *et al.*, 2013) (Jiandong *et al.*, 2017); Singapore (Quarmby and Santos, 2019), Vietnam (Peilei *et al.*, 2019)) the declination was well explained. In comparison, PM10's concentration seen in Beijing, China drastically declined from 115.2 μg/m^3 in 2013 to 78.5 μg/m^3 in 2017 (Environment, 2019), which was consistently higher than Long Bien. On the other hand, compared to the same period in Singapore (31 μg/m^3 in 2013 - 25 μg/m^3 in 2017) (Annual Air Pollution level of PM10 and PM2.5 in Singapore from 2007 to 2018, 2020), PM10's concentration in Vietnam had higher concentration. The moderate shift of PM10 concentration in Long Bien, Hanoi can be explained by increased economic and traffic-intensified activities in a recent study in 2018 (Markus *et al.*, 2019).

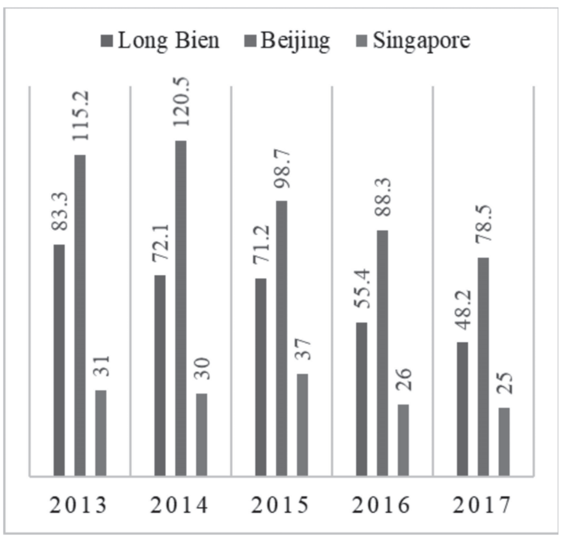

Fig. 2. Comparison of PM10 concentration in Long Bien (Hanoi), Beijing (China), Singapore (Singapore) from 2013 to 2017.

PM2.5 dust concentration in Long Bien, Hanoi in the years 2013-2017 (Figure 3) also saw a decrease. ranging from 58.5 to 35.8 (μg/m^3). Throughout the years, PM2.5 dust concentration was consistently higher than the permitted standard of 25 (μg/m^3) by Vietnam Ministry of Natural Resources and Environment (QCVN 05: 2013/BTNMT). This decreasing trend is consistent with concurrent declining tendency of air pollutant's concentration measured in 2013 - 2019 report by Ministry of Natural Resources and Environment (Environment V. M., 2019).

While comparing to PM2.5's concentration in Beijing and Singapore, an overall decline trend was again observed (Figure 4). PM2.5 concentration in Long Bien district was lower in comparison to

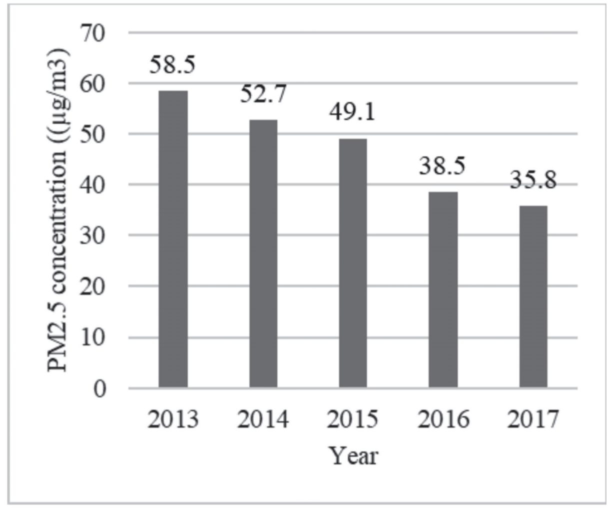

Fig. 3. PM2.5 concentration in 2013-2017 in Long Bien, Hanoi

PM2.5's concentration measured in Beijing, China from 2013 (82.1 μg/m^3) to 2017 (61.3 μg/m^3) (Environment, 2019), but higher than PM2.5's concentration measured in Singapore from 2013 (20 μg/m^3) to 2017 (14 μg/m^3) (Annual Air Pollution level of PM10 and PM2.5 in Singapore from 2007 to 2018, 2020).

Seasonal variability of PM2.5 and PM10 concentration

Northern part of Vietnam has a tropical monsoon climate with four distinct seasons: spring, summer, autumn and winter; two wind seasons: the Northeast cold monsoon wave in the winter (from September - October to next year's March and April)

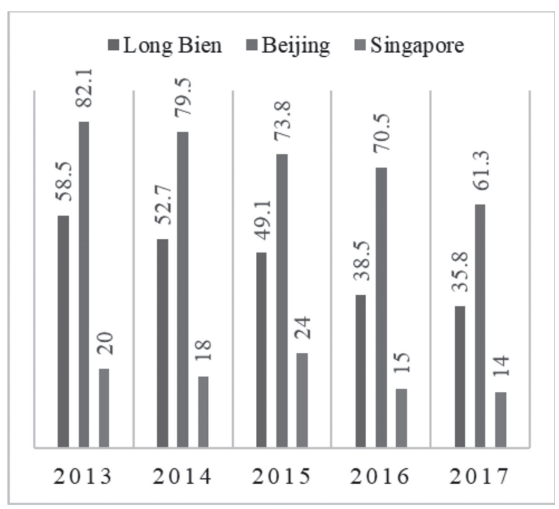

Fig. 4. Comparison of PM2.5 concentration in Long Bien (Hanoi), Beijing (China), Singapore (Singapore) from 2013 to 2017.

and the Southwest hot and dry waves and the Southeast humid waves in the summer (from May to August). The fluctuation trend of PM10 and PM2.5 in Long Bien area, Hanoi depends on climatic conditions, including seasonal and weather variety. Figure 5 shows the concentration of PM10 and PM2.5 by months from 2013 to 2017 in this area. Overall, PM10 and PM2.5's concentration values were particularly high in October to March, and lower in April and September (Table 2). The highest concentration was usually seen in December and January (82.1 - 89.2 μg/m^3) due to the region's characteristic winter. The Northeast monsoon active in the winter would bring dust and pollutants from distant sources, while dry withering weather along with high air pressure preserves the high concentration of PM in the atmosphere. In contrast, under the influence of both Southwest and Southeast winds blowing into the sea or northward, with frequent rains, PM concentration in the summer was greatly reduced. PM 10 and PM2.5's concentration were lowest in July and August. This result is compatible with the trend observed in some studies on seasonal fluctuations of PM in Northern Vietnam (Hoang *et al.*, 2014) (Pham, Vu, Hoang, Do, and Luong, 2002) (Chu and Nguyen, 2012).

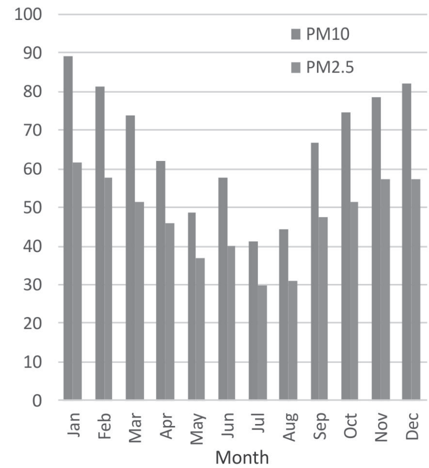

Fig. 5. Average concentration of PM10, PM2.5 monthly from 2013 to 2017.

Temporal variability of the PM2.5/PM10 ratio from 2013 to 2017

PM2.5 and PM10 are produced from different sources and have various impacts. PM10 can also be mainly composed of PM2.5. PM2.5/PM10 ratios is often used as an important indicator of the fine particles to determine PM distribution in the atmosphere, therefore analyze the underlying atmospheric processes within the local environment. This ratio varied by place, time, exhaustion sources and weather condition. As measured in several research, PM2.5/PM10 ratio in Milan, Italia was 0.61 to 0.63 (Marcazzan *et al.*, 2001); in Beijing, China was 0.54 (Sun *et al.*, 2006); Hong Kong was 0.53 to 0.78 (Environment A. A., 2003); Switzerland was 0.75 to 0.76 (Gehrig and Buchmann, 2003); and in Middle and Central European countries was 0.55 to 0.78 (Pastuszka, 2001).

As shown in Table 3, over the years, PM2.5/PM10 ratios had fluctuated in the range from 0.69 to 0.74. While taken into consideration of seasonal changes (Figure 6), PM2.5/PM10 ratios was highest in May (0.76) and lowest in January (0.67). It was inferred that the dust ratio varies from month to month, possibly due to the source of emissions and climatic conditions in this area.

Table 2. Average concentration of PM10, PM2.5 monthly from 2013 to 2017.

Month	PM 10 concentration (μg/m^3)	PM 2.5 concentration (μg/m^3)
Jan	89.20	61.55
Feb	81.40	57.79
Mar	73.70	51.59
Apr	62.10	45.95
May	48.70	37.01
Jun	57.80	39.88
Jul	41.20	29.66
Aug	44.50	31.15
Sep	66.70	47.36
Oct	74.70	51.54
Nov	78.60	57.38
Dec	82.10	57.47

Table 3. PM2.5/PM10 ratio from 2013 to 2017

Year	PM2.5 concentration (μg/m^3)	PM10 concentration (μg/m^3)	PM2.5/ PM10
2013	58.5	83.3	0.70
2014	52.7	72.1	0.73
2015	49.1	71.2	0.69
2016	38.5	55.4	0.69
2017	35.8	48.2	0.74

Comparing this figure with PM2.5/PM10 ratios in the same period in Beijing and Singapore (Figure 7), Hanoi was in the average position. While both Beijing's and Hanoi's figure increased over the years, Singapore's PM2.5/PM10 ratios decreased slightly from 0.65 (2013) to 0.56 (2017).

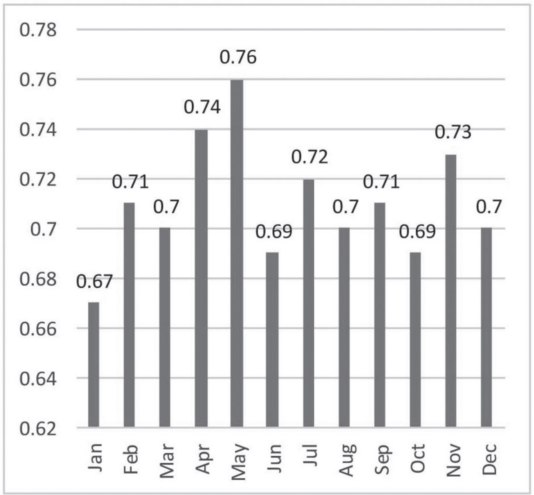

Fig. 6. Average PM2.5/PM10 ratio by month from 2013 to 2017 in Long Bien, Hanoi

Assessment of ecological environmental risks related to PM

The results of calculating the ecological environment risk due to the impact of PM dust in Long Bien indicated the effect of PM to the ecological environment. From the year 2013 to 2016, the ecological environment in Long Bien area experienced constant high risks for PM10. In 2017, the situation decreased into average risks with PM10. For PM2.5, in the years of 2013 to 2017, high risk for the ecological environment in Long Bien was consistent (Table 4)

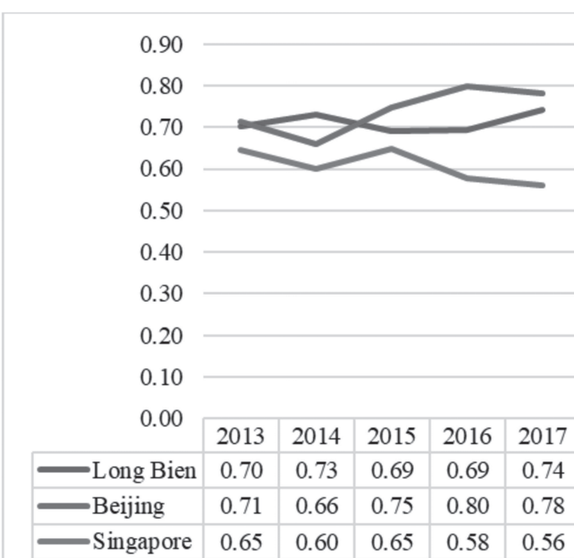

Fig. 7. Comparison of PM2.5/PM10 ratio in Long Bien (Hanoi), Beijing (China), Singapore (Singapore) from 2013 to 2017.

Table 4. Risk Quotient of PM10 and PM2.5 from 2013 to 2017.

Year	Risk Quotient (PM10)	Risk Quotient (PM2.5)
2013	1.666 (> 1)	2.34 (> 1)
2014	1.442 (> 1)	2.108 (> 1)
2015	1.424 (> 1)	1.964 (> 1)
2016	1.108 (> 1)	1.54 (> 1)
2017	0.964 (0.1- 1)	1.432 (> 1)

Assessment of health risks associated with exposure to PM10

Attributable health risk associated with PM10 dust exposure in the years 2013-2017 ranges from 1.03 (2017) to 1.06 (2017). Recorded value is higher than observed in North America (RR = 1.02) (Hamra *et al.*, 2014) and lower than New Zealand (RR = 1.16) (Hales *et al.*, 2012). The results indicated mortality rate contributed by PM10 exposure in Long Bien ranged from 3.01% to 5.7%. This figure is 1.96% higher than in North America (Hamra *et al.*, 2014), while being much lower compared to New Zealand (Hales *et al.*, 2012) (Table 5).

Table 5. Attributable health risks and mortality rate due to exposure of PM10

Area	Year	RR	ER
Long Bien, Hanoi	2013	1.06	5.70
	2014	1.05	4.85
	2015	1.05	4.78
	2016	1.03	3.57
	2017	1.03	3.01
North America	-	1.02	1.96
New Zealand	-	1.16	13.79

Assessment of health risks related to exposure for PM2.5

Attributable health risk associated with PM2.5 exposure in the years 2013-2017 ranges from 1.67 (2017) to 1.87 (2013). This value is lower than China's (RR = 2.35) (Zou *et al.*, 2018). Attributable morbidity rate contributed by PM2.5 exposure in Long Bien areas ranges from 40.27% to 46.57%. As comparing to data in China (57.47) (Zou *et al.*, 2018), this rate is approximately 10.9% lower.

DISCUSSION

Long Bien area has seen a negative trend in concentration of PM10 and PM2.5 throughout the period of 2013 to 2017. PM concentration was

Table 6. Attributable health risks and morbidity rate due to exposure of PM2.5

Area	Year	RR	ER
Long Bien, Hanoi	2013	1.87	46.57
	2014	1.82	45.28
	2015	1.80	44.39
	2016	1.70	41.24
	2017	1.67	40.27
China	-	2.35	57.47

consistently higher than the permitted Vietnam national standard. Highest concentration of both PM2.5 and PM10 were observed in December and January due to the region's winter and monsoon season. In contrast, the figures were lower in the summer under the effect of both Southwest and Southeast winds blowing into the sea or northward, with frequent rains. It is concluded that PM concentration is associated with seasonal and wind variety, which in turn suggest a compatable measuring mechanism in place for environmental health monitoring.

PM2.5/PM10 ratio varied at time, without a consistent decline. It can be concluded that 69-74% of PM10 is composed by fine articles of PM2.5 from studied period, reflecting the severity of fine particular pollution in Long Bien area.

From comparison to two cities in the region, PM10, PM2.5's concentration and PM2.5/PM10 ratio remained in average position, all figures were lower than observed in Beijing but higher than observed in Singapore. This can be explained by different public health policies in place in three cities. Where China and Vietnam are still adopting the "Develop first - recover later" in many policies regarding environmental protection (Markus *et al.*, 2019) (Peilei *et al.*, 2019), Singapore has seen drastic changes in urban planning and green initiatives to limit the emission (Hesketh *et al.*, 2017). This result could in turn serve as a reflection and learning opportunity for stakeholders in Vietnam to revise and improve current mechanism toward a more sustainable eco-friendly city development.

High risks to the ecological environment was consistently observed for both PM2.5 and PM10. The highest risk quotient calculated for both PM10 and PM2.5 were recorded in 2013 (1.666 for PM10 and 2.34 for PM2.5). Even though the figure gradually decreased over the years, the situation still remains, especially for PM2.5.

Meanwhile, health risks associated with both PM2.5 and PM10 exposure in Long Bien area saw steady decrease from 2013 to 2017. The result showed as exposed to PM10, mortality risk was 1.03 to 1.06 times higher, and mortality rate contributed by short-term exposure to PM10 in Long Bien ranged from 3.01% to 5.7%. While risk of lung cancer was 1.67 to 1.87 times higher from exposure to PM2.5, morbidity rate contributed by long-term exposure to PM2.5 40.27% to 46.57%.

However, the study has some limitations. Firstly, the authors acknowledged the lack of variability in time-series data on particulate matters. The use of available data from one air monitoring station may limit the study's scope to assess spatial and temporal variability of particulate matters in different districts of Hanoi.

Secondly, since data of health impacts of air pollution still remains scarce and limited to academic study only, the authors were not able to calculate relative risk for mortality and mobility in detailed for both PM2.5 and PM10. Attention in healthcare facilities to air pollution's health impacts is necessary in the future as the air quality has become an emerging environmental health problem in Vietnam. These data could be used for monitoring and policy-making purpose, as well as future studies.

Also the lack of diversity between particulate matters and other air pollutants is acknowledged, since exposure to different air pollutants is navigated into only particulate matter. Particulate matter exposure (PM10 and PM2.5 in particular) is highly recognized by many studies as the cause for mortality and morbidity due to air pollution, therefore chosen to be representative in this study. Moreover, due to limited resource in monitoring devices, the study could not comprehend individual exposure level for different pollutants. These health effects are not included in the study's scope, and further studies on air pollution exposure in Hanoi is necessary.

Lastly, it is noteworthy that relative risk and attributable health risk from PM2.5 and PM10 exposure were not compared to studies and reports in Vietnam, due to the lack of comparable data. Therefore, the study's scope on ecological impact and health risk assessment is conservative.

CONCLUSION

The trend of PM2.5 and PM10 concentration exceeding the limits in national standard throughout the years indicated that air pollution control in Long

Bien area in particular and in Hanoi city in general remains an environmental health issue. PM concentration varies month by month, mostly affected by seasonal changes and monsoon season. From comparison with Singapore and Beijing, the author suggest adaptation in monitoring and quality control process in sustainable development. Further high risk in public health and ecological health is signal for comprehensive intervention and policies from stakeholders, while emphasizing the need for further research of particular matter in Vietnam.

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