ESTIMATING HEALTH BURDEN AND ECONOMIC LOSS ATTRIBUTABLE TO PM$_{2.5}$ POLLUTION IN AMBIENT AIR IN URBAN AREAS IN VIETNAM

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ABSTRACT

PM$_{2.5}$ pollution had been a global public health problem, leading risk factor for Disability-Adjusted Life Years in 2019. In Vietnam, air pollution has been increasing rapidly in urban areas, resulting in adverse impacts on public health. This study aims to estimate the health burden attributed to ambient PM$_{2.5}$ pollution and cost loss in 2016–2019 period in Hanoi and Ho Chi Minh City. Exposure-response function was used to estimate the health impacts and statistical life (VSL), cost of illness (COI), and human capital approach (AHC) were applied for external cost estimation. The results showed that the predominance of the respiratory diseases was in children and cardiovascular mortality diseases prevailed in adults. Female was more affected by cardiovascular premature deaths and male was more affected by lung cancer and respiratory fatalities. In 2016-2019 period, the average annual cost for the reduction of health effects was equivalent to 0.09% and 0.04% of GDP in Hanoi and Ho Chi Minh City, respectively. The adverse health caused by PM$_{2.5}$ exposures should not be neglected in Vietnam.

INTRODUCTION

In recent years, due to the rapid growth of urbanization and industrialization in Vietnam, air pollution has caused alarming problems including serious threats to the public health. Based on the annual Environmental Performance Index (EPI) report from Yale and Columbia universities in 2012, Vietnam was one of the top ten countries regarding air pollution in Asia (EPI, 2020). Big cities, such as Hanoi and Ho Chi Minh, have faced a high concentration of pollutants, especially of fine particles (PM$_{2.5}$), beyond the National Technical Regulation on Ambient Air Quality in many days (Monre, 2018; Nguyen *et al.,* 2018). Nguyen *et al.* (2018) reported that in Hanoi the annual average concentration of PM$_{2.5}$ exceeded 2 to 3 folds of the National Technical Regulation on Ambient Air Quality (QCVN 05/2013) and 4 to 7 folds of the WHO recommended value in the period between 2010 and 2015. Although the air quality in Ho Chi Minh City was better than in Hanoi, the annual PM$_{2.5}$ concentrations still exceeded the recommended values. The high concentration of PM$_{2.5}$ was associated with an increase in chronic obstructive pulmonary disease and cardiovascular morbidity and mortality (Ni *et al.,* 2015, Hayes *et al.,* 2020). Cohen *et al.* (2017) reported 4.2 million deaths and 103.1 million disability-adjusted life-years (DALYs) in 2015 due to ambient PM$_{2.5}$ exposure, accounting for 7.6% of total global deaths and 4·2% of global DALYs, 59% of these cases was in East and South Asia. Vu *et al.* (2020) estimated about 1136 deaths associated with long-term PM$_{2.5}$ exposure in Ho Chi Minh City when PM$_{2.5}$ concentration was 2.3 times higher than the WHO guideline (10 µg/m³).

Ho (2017) estimated that exceedance of WHO guidelines of PM$_{10}$ was associated with 5 deaths/year and 204 deaths/year in District 5 and Ho Chi Minh City, caused an economic loss of 1.84 billion

USD per year. In Hanoi, 3000 extra deaths were attributed to traffic-related PM$_{10}$ in 2012 (Hieu *et al.* 2013). There are still limited studies on evaluating the short- and long-term effects of PM$_{2.5}$ on public health and estimating the economic loss from health burden in Ho Chi Minh City and Ha Noi. Therefore, the purpose of the current study is to (1) analyze the temporal variation of PM$_{2.5}$ in the period of 2016 to 2019; (2) estimate the health burden attributed to PM$_{2.5}$ exposure; (3) evaluate the economic loss of health burden. The obtained results will provide a scientific basis for policy-makers to formulate appropriate policies for air pollution management strategies.

MATERIALS AND METHODS

Study area

The study was conducted at the two cities: Hanoi and Ho Chi Minh City in Vietnam. Hanoi is the capital of Vietnam, located in the North and is the second-largest city in the country with an area of 3358 km^2 and a population of approximately 7.4 million (GSO 2018). Hanoi has a tropical monsoon climate with two monsoon seasons, including the Northeast monsoon during winter and the Southeast monsoon during summer. Ho Chi Minh is the biggest city in Vietnam, with a total area of 2095 km^2 and more than 7 million people (GSO Vietnam, 2017). The climate has two main seasons, the rainy season (May to November) and the dry season (December to April of the following year). The environmental quality in the two cities is strongly affected by the socio-economic development, which has contributed on serious air pollution in Vietnam in recent years.

Data sources

The data of PM$_{2.5}$ concentrations from 2016 to 2019 in Hanoi and Ho Chi Minh City was obtained from US embassy monitoring stations located at 7 Lang Ha, Ba Dinh Ha Noi and at 4 Le Duan, District 1, Ho Chi Minh City. The monitoring equipment is Met One's BAMs. Monitoring data is available at www.airnow.gov. The profile of health data for Vietnam was obtained from The Institute for Health Metrics and Evaluation (IHME). The health data is available at: http://ghdx.healthdata.org/. The economic data was referenced from World Bank and health Metrics and Evaluation and is available at: https://data.worldbank.org.

Health burden assessment

PM$_{2.5}$ exposure is related to various adverse health impacts such as respiratory diseases, cardiovascular diseases, hypertension, stroke, diabetes, lung cancer, and brain damages (Hayes *et al.,* 2020; Li *et al.,* 2017). The health endpoints in this study were defined as six main categories of diseases related to the PM$_{2.5}$ exposures in the ICD-10 disease classification of WHO including circulatory system diseases; respiratory diseases; endocrine, nutritional and metabolic diseases; neoplasms; mental and behavioral disorder and nervous system diseases (ICD-10, 2016). The disease codes ranged as followed: respiratory mortality system [J00-J99]; lung cancer [C33-C34]; cardiovascular mortality [I27, I51]; respiratory diseases [J20-J22, J41, J45].

In this study, the log-linear exposure-response function was used to estimate the health burden associated with PM$_{2.5}$ exposure (Vu *et al.,* 2020; Yin *et al.,* 2017; Yao *et al.,* 2020; Shang *et al.,* 2013). The number of cases E with specific health outcomes attributed to PM$_{2.5}$ among the exposed population (P) can be estimated by the following equation

$$E = P \times Io \times \left(1 - \left(\frac{1}{\exp(\beta * (C - Co))}\right)\right) \qquad .. (2)$$

Where, P is the exposed population which is the population of Hanoi and Ho Chi Minh City obtained from General Statistic Office of Vietnam. I$_0$ is the baseline incidence rate of certain health endpoint of the exposed population. b is the exposure-response coefficient obtained from the epidemiological studies, which related to a specific change in pollutant concentration (Table 1). C is the PM$_{2.5}$ concentrations in investigated cities (µg/m^3); C$_0$ is the baseline PM$_{2.5}$ concentrations. In this study, health assessment of short-term and long-term effects was conducted with two scenarios: the first scenario used C0 = 10µg/m^3 as recommended by WHO, and the second applied the threshold of PM$_{2.5}$ C0 = 25µg/m^3 regulated by National Technical Regulation on Ambient Air Quality (QCVN 05/2013).

Estimation of economic loss

The common approaches to evaluate economic cost associated with health loss attributed to air pollution include Value of statistic life (VSL), amended human capital (AHC) and Cost of illness (COI) (Bui *et al.,* 2020); (Yin *et al.,* 2017). VSL is computed as the monetary value for a small reduction of mortality risk according to individual preferences. VSL

Table 1. PM$_{2.5}$ exposure-response coefficients and baseline incidence rates for the analyzed health endpoints

Heath endpoint	Exposure time	Population	b	Reference
Cardiovascular mortality	Longterm	Male	5.19E-04	(Franklin *et al.*, 2007)
Respiratory mortality	Longterm		1.88E-03	(Franklin *et al.*, 2007)
Lung cancer	Longterm		3.40E-03	(Franklin *et al.*, 2007)
Cardiovascular mortality	Longterm	Female	1.29E-03	(Franklin *et al.*, 2007)
Respiratory mortality	Longterm		1.56E-03	(Franklin *et al.*, 2007)
Lung cancer	Longterm		3.40E-03	(Franklin *et al.*, 2007)
Cardiovascular	Short-term	Male	1.09E-03	(Ren *et al.*, 2021)
Respiratory	Short-term		1.69E-03	(Ren *et al.*, 2021)
COPD	Short-term		1.88E-03	(Ren *et al.*, 2021)
Hypertension	Short-term		6.98E-04	(Ren *et al.*, 2021)
CHD	Short-term		1.39E-03	(Ren *et al.*, 2021)
Stroke	Short-term		1.19E-03	(Ren *et al.*, 2021)
Asmtha	Short-term		2.10E-03	(Ko *et al.*, 2007)
Cardiovascular	Short-term	Female	1.19E-03	(Ren *et al.*, 2021)
Respiratory	Short-term		2.18E-03	(Ren *et al.*, 2021)
COPD	Short-term		2.27E-03	(Ren *et al.*, 2021)
Hypertension	Short-term		1.49E-03	(Ren *et al.*, 2021)
CHD	Short-term		1.19E-03	(Ren *et al.*, 2021)
Stroke	Short-term		8.96E-04	(Ko *et al.*, 2007)
Asmtha	Short-term		2.10E-03	Ko *et al.*, 2007
Cardiovascular	Short-term	0-14 year	7.13E-04	(Luong *et al.*, 2017)
Respiratory	Short-term		2.18E-03	(Phung *et al.*, 2016)
Stroke	Short-term		1.47E-03	(Bui *et al.*, 2020)
Asmtha	Short-term		1.76E-03	(Bui *et al.*, 2020)

presented individual willingness to pay for preventing the anonymous premature death from exposure to air pollution (Etchie *et al.*, 2017). COI referred to the cost of the disease in terms of medical treatment, hospitalization, and productive lost (Yao *et al.*, 2020). The human capital approach calculates the loss of individual productivity or labor capital due to off-work (Huang *et al.*, 2012). Different methods in estimating the health-related costs during short-term or long-term exposure to air pollution resulted in different monetary values.

The VSL is the assessment of the risk of premature death. Previous studies used the benefit-transfer method and OECD reports to estimate VSL in Vietnam following Bui *et al.* (2020); Kim *et al.* (2019).

$$VSL_{Vietnam.2011(VND)} = VSL_{OECD.2011(USD)} \times \left(\frac{Y_{Vietnam.2011}}{Y_{OECD.2011}}\right)^e \quad (1)$$

Where, VSL$_{Vietnam, 2011}$ is the VSL value of Vietnam in 2011 in Vietnam Dong, VSL$_{OECD,2011}$ is the average baseline values of OECD group of countries in USD, Y$_{Vietnam, 2011}$ is the GDP per capita based on Purchasing Power Parity method (PPP) in USD. PPP was used to convert the currency from USD to VND in this study. e is the income elasticity and was chosen to be 1.3 when calculating VSLVietnam (according to

World Bank and Institute for Health metrics and Evaluation, 2016).

The VSL$_{Vietnam}$ for the period of 2012 to 2019 was estimated basing on VSL$_{Vietnam, 2011}$ (Bui *et al.*, 2020; Kim *et al.*, 2019).

$$VSL_{Vietnam 2012-2019(VND)} = (VSL_{Vietnam.2011(USD)} \times (1 + \% \Delta P_{2011-2019})^e \times (1 + \% \Delta Y_{2011-2019})^e) \times PPP_{2019} \quad (2)$$

where VSL$_{Vietnam, 2011,}$ USD is the VSL value of Vietnam in 2011 (USD), $\Delta P_{2011-2019}$ is the percentage increase of consumer price from 2011 to 2019 (%), $\Delta Y_{2011-2019}$ is the percentage of real GDP growth per capita from 2011 to 2019 (%), PPP is exchange rate adjusted based on purchasing power parity (PPP) in 2019. The PPP conversion coefficient and GDP in the period 2012-2019 was obtained from the World Bank data

The COI for hospital admissions related to cardiovascular, respiratory, asthma, stroke diseases was estimated by Yin *et al.* (2017); Yao *et al.* (2020):

$$COI_j = COI_j + DGDP \times T_j \quad .. (3)$$

where COI is the average medical treatment cost for a disease j for each case. DGDP is the GDP per capita per day, T$_j$ is the average labor time lost due to disease j for each case. In Vietnam, up-to-date data on medical costs are not available. Therefore, in

the current study, medical cost was taken from the study of Bui *et al.*, 2020.

The human capital approach (AHC) was used to evaluate the human capital loss (HCL) due to premature death as Yin *et al.* (2017); Hou *et al.* (2012),

$$HCL = \sum_{i=1}^{t} GDP_i^{dv} = GDP_o \sum_i^t \frac{(1+\alpha)^i}{(1+r)^i} \quad .. (4)$$

where GDP$_i^{dv}$ is the discounted value (dv) of per capita GDP in the ith year in Vietnam, t is the average time of life-year loss due to PM$_{2.5}$ (assumed to be 10 years), GDP0 is the per capita GDP in a basic year in Vietnam, α is the per capita GDP growth rate, r is the social discount rate, which was obtained from World Bank data.

RESULTS AND DISCUSSION

Temporal variation of Concentrations of PM$_{2.5}$

The temporal variation of PM$_{2.5}$ concentration in Hanoi and Ho Chi Minh city is shown in Fig. 1. Daily and annual PM$_{2.5}$ concentrations in both cities exceeded the recommended value of WHO guideline of 25 µg/m³ for daily and 10 µg/m³ for annual levels. As compared to the recommended values of the National Technical Regulation on Ambient Air Quality, only daily PM$_{2.5}$ concentrations in Hanoi in the period of 2017-2018 were beyond the threshold. A significant variation of PM$_{2.5}$ concentration between the dry (November to March) and wet seasons (April to September) were observed in Hanoi, whereas the seasonal trend was not clear in Ho Chi Minh City. From 2016 to 2019, the average daily PM$_{2.5}$ concentration varied from 41 to 69.6 µg/m³ (mean: 36.1±2.5 µg/m³) in the dry seasons, and from 22.9 to 58.2 µg/m³ (mean: 61.3± 3.67 µg/m³) in the wet seasons in Hanoi. The concentration of PM$_{2.5}$ was in the range of 20 to 34.2 µg/m³ (mean 25.3 ±5.67 µg/m³) in the wet seasons, and 21 to 37.9 µg/m³ (mean 30.7±2.45 µg/m³) in the dry seasons in Ho Chi Minh City. The difference in PM$_{2.5}$ concentrations between Hanoi and Ho Chi Minh can be due to the difference in meteorological conditions, topographical characteristics, and emissions. In Hanoi, the significantly higher PM$_{2.5}$ in the dry season may be attributed mainly to longrange transport from either Island China through inland China from November to January or via the Gulf of Tonkin from January to March. The longrange transport was strongly influenced by the north and northeast monsoons (Thuy *et al.,* 2018' Cohen *et al.,* 2010). In summer PM$_{2.5}$ concentration

decreased since PM$_{2.5}$ could be carried to the sea with the south-east wind or washed out by rain. In Ho Chi Minh City weather is mild and less seasonal variation. The climate was less influenced by the northeast monsoon due to the proximity to the equator and the separation from the North by the Hai Van pass. Therefore, the PM$_{2.5}$ concentrations do not fluctuate seasonally. In addition, the topography with hills and mountains surrounding Hanoi may prevent to the dispersion of PM$_{2.5}$ resulting in PM$_{2.5}$ accumulations within the city. Meanwhile, Ho Chi Minh has a long coastline facilitating the dispersion of air pollutants to the sea. As a result, the PM$_{2.5}$ concentrations in Ho Chi Minh city are lower than in Hanoi.
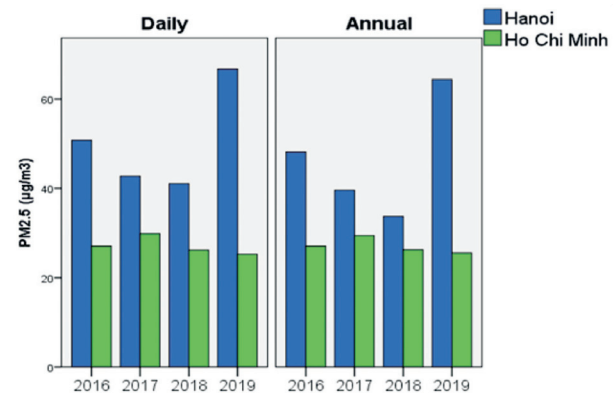

Fig. 1. Variation of PM2.5 in Hanoi and Ho Chi Minh from 2016 to 2019

Health burden due to PM$_{2.5}$

Health impact of ambient PM$_{2.5}$ exposure

Mortality and hospital admission for categorized diseases were estimated using linear exposureresponse function under two scenarios: (1) baseline PM$_{2.5}$ is the WHO guideline for air quality, and (2) baseline PM$_{2.5}$ is the QCVN 05/2013 for ambient air quality in Hanoi and Ho Chi Minh City, presented in Fig. 2 and Fig. 3.

With the PM$_{2.5}$ baseline value as WHO guideline from 2016 to 2019, it was estimated that the total number of deaths associated with cardiovascular, respiratory diseases, and lung cancer was in the range of 565 to 1291 cases, whereas hospital admission cases related to cardiovascular, asthma, stroke, and respiratory diseases varied from 14387 to 37745 cases in Hanoi. These estimated results were corresponding to 11 fatalities and 285 morbidities per 100000 population per year in Hanoi. With the same disease profile, the number of mortalities varied from 426 to 507 cases and those of
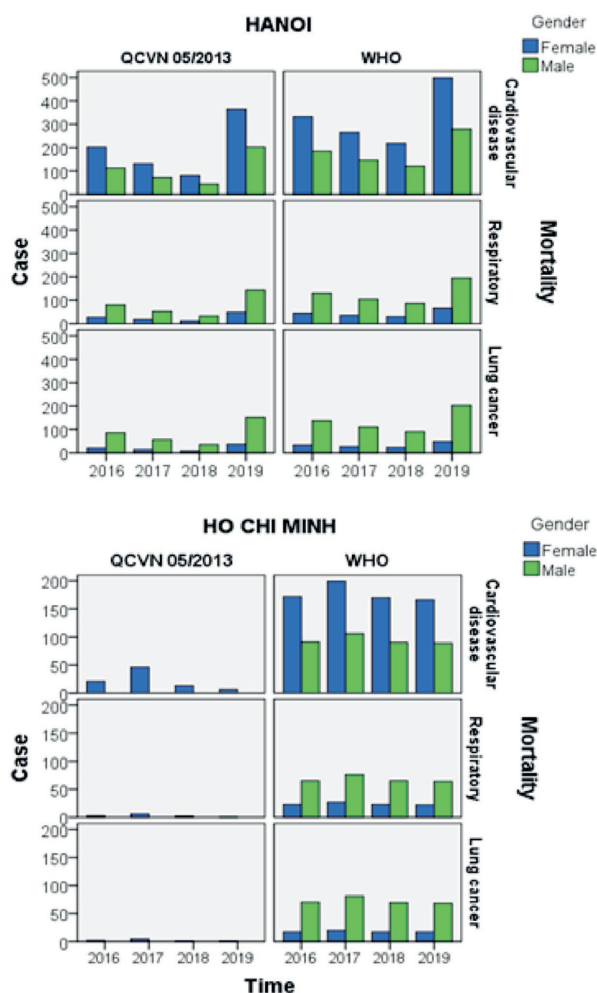
Fig. 2. The mortality cases in cities by gender in two scenarios from 2016 to 2019

Fig. 3. The hospital admission cases in two cities by gender in two scenarios from 2016 to 2019

morbidities ranged from 483 to 7347 cases in Ho Chi Minh city, which was equal to 5 mortalities and 34 hospital admission cases in 100000 population per year.

The number of deaths and hospital admission cases decreased significantly for both cities when the $PM_{2.5}$ baseline value was conformed to QCVN 05/2013, which was less strict. The total fatalities linked to diseases referred above, ranged from 211 to 946 cases in Hanoi and 16 to 118 cases in Ho Chi Minh, respectively, which was corresponding to 6 deaths and roughly 1 death in 100000 population per year in Hanoi and Ho Chi Minh, respectively. The morbidities in Hanoi reached 15395 cases, whereas that in Ho Chi Minh were not estimated since the concentrations of $PM_{2.5}$ from 2016 to 2019 was less than the baseline value.

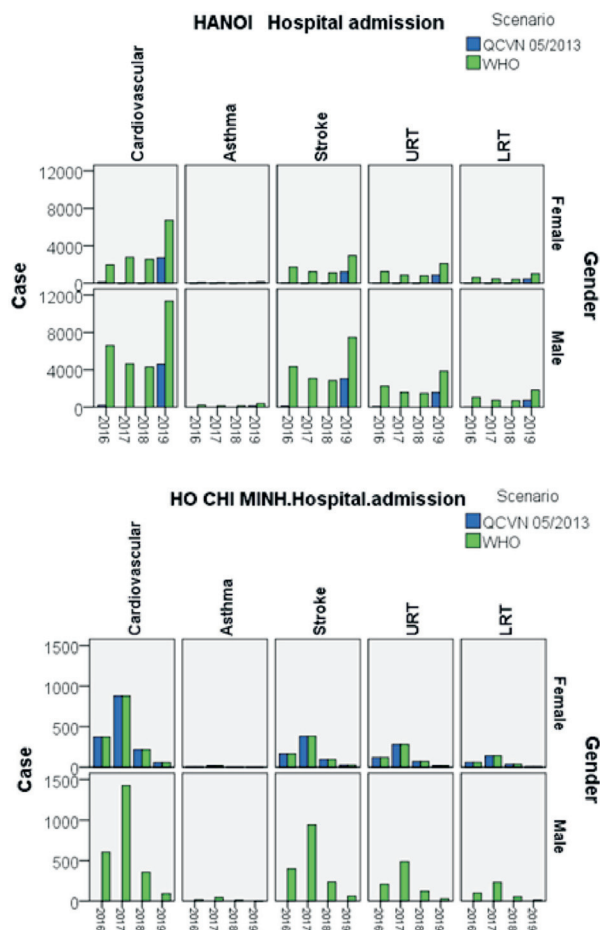Comparing the two cities in the two scenarios, the average annual deaths due to exposure to $PM_{2.5}$ in Hanoi was roughly 2 times and 9 times higher than those in Ho Chi Minh City, when the baseline values of $PM_{2.5}$ were WHO guideline and QCVN 05/2013, respectively. Meanwhile, there were average annual increases of 19505 cases and 4010 cases in hospital admission in Hanoi in the scenario of WHO guideline and QCVN 05/2013, respectively. The lower the $PM_{2.5}$ concentrations and less strict the baseline values resulted in the decrease of mortalities and morbidities. For long term health effects in the period of 2016 to 2019, the annual mortality rate decreased 27- 63% in Hanoi and 76- 96% in Ho Chi Minh City, respectively. For shortterm health effects, the daily $PM_{2.5}$ levels in Ho Chi Minh City remained below the regulated values of QCVN 05/2013, indicating a safe limit. Consequently, no estimated cases of morbidities related to $PM_{2.5}$ exposure recorded in Ho Chi Minh City.

Among disease vectors, cardiovascular diseases

accounted for the majority of fatalities and morbidities in this study. Our results was consistent with earlier studies in Ho Chi Minh City where death related to cardiopulmonary diseases accounted for 63%, in Guangzhou where the number of premature mortalities due to cardiovascular and respiratory diseases contributed 73% and higher cardiovascular fatalities observed in Thailand where the death rate from cardiovascular disease is 7 times higher than from respiratory disease (Pinichka *et al.,* 2017; Ding *et al.,* 2016, Vu *et al.,* 2020). It was plausible that PM increased cardiovascular risk through induction of pro-hypertensive vasoconstriction and the predisposition to arrhythmias (Du *et al.,* 2016). These fatalities caused by PM$_{2.5}$ observed in this study agreed with the A6 mortality reporting system in Vietnam, in which circulatory disease, cancer, and injury were three leading causes of death in Vietnam (Stevenson *et al.,* 2015).

Health damage changes across gender

Gender dependent health burden of mortality and morbidity cases was presented in Table 2, Table 3 in two scenarios.

Table 2. The number of premature deaths due to PM$_{2.5}$ exposure by gender (according to WHO guideline)

Health endpoint	Mortality cases attributed to PM$_{2.5}$ in gender							
	Male				Female			
	2016	2017	2018	2019	2016	2017	2018	2019
Hanoi								
Respiratory mortality	130	104	86	195	44	35	29	66
Cardiovascular mortality	184	146	120	279	332	264	217	498
Lung cancer mortality	137	110	91	203	33	26	22	48
Ho Chi Minh								
Respiratory mortality	65	76	65	64	23	27	23	22
Cardiovascular mortality	91	106	90	89	172	199	170	166
Lung cancer mortality	70	81	69	68	17	20	17	17

The average annual death incidence related to respiratory, cardiovascular, and lung cancer was 29%, 41%, and 30% in males and 11%, 81%, and 8% in females in both cities, respectively. The average annual numbers of medical care for cardiovascular, asthma, stroke, and respiratory diseases accounted for 17.8%, 0.4%, 7.8%, and 8.4% for the total cases in females, and the corresponding values for males comprised of 29.9%, 1%, 19.7% and 15%. There is a significant discrepancy in the mortality cases of disease vectors between females and males. The

Table 3. The number of premature deaths due to PM$_{2.5}$ exposure by gender (according to QCVN 05/ 2013)

Health endpoint	Mortality cases attributed to PM$_{2.5}$ in gender							
	Male				Female			
	2016	2017	2018	2019	2016	2017	2018	2019
Hanoi								
Respiratory mortality	80	52	32	143	27	18	11	49
Cardiovascular mortality	112	72	44	203	203	131	81	364
Lung cancer mortality	85	56	35	151	20	13	8	36
Ho Chi Minh								
Respiratory mortality	8	18	5	2	3	6	2	1
Cardiovascular mortality	11	24	7	3	21	46	13	6
Lung cancer mortality	9	19	6	3	2	5	1	1

number of premature cardiovascular deaths in females was higher than in males, and fatalities from lung cancer and respiratory disease was higher in males than in females, which were observed in both cities. Our obtained results were consistent with the study of Franklin *et al.* (2007) in the USA, where females bore the more negative impact on cardiovascular mortality than males, and males had more negative response to respiratory deaths than females. In Hanoi, annual death cases related to cardiovascular diseases for females were roughly double of males (4 cases for female and about 2 cases for male per 100000 population), whereas annual death cases related to lung cancer and respiratory disease for males were approximately four-folds higher than females (1 case for female and 4 cases for male per 100000 population). A difference in gender in hospital admission cases was also observed in our study. The morbidity cases linked to respiratory, cardiovascular, asthma, and stroke reported in males were two folds higher than in females every year (187 cased for male and 98 cases for female in 100000 population, respectively) in Hanoi. The similar trend of mortalities and morbidities by gender were found in two studied cities.

Health damage changes across age

The function of health damage depends on several factors such as age, gender, lifestyle, and the surrounding environment condition. The health loss due to disease treatment was estimated in the two cities according to two scenarios (QCVN 05/2013 and WHO guideline) and by age groups. The results were shown in Fig. 4.

For Hanoi, when applying the PM$_{2.5}$ level suggested by the WHO guideline as the baseline, the
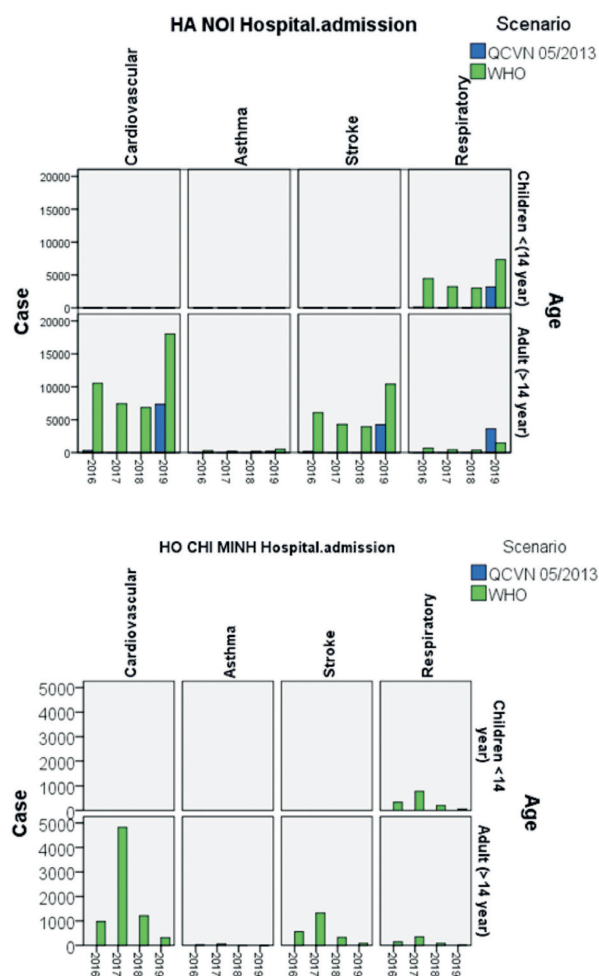
Fig. 4. The hospital admission cases in two cities by age in two scenarios from 2016 to 2019

hospital admission related to respiratory diseases accounted for almost all cases in children (0-14 years old), which ranged from 2996 to 7362 cases in the 2016-2019 period. The other diseases (stroke, asthma, and cardiovascular) were negligible in children. For adults (>14 years old), the predominant diseases were cardiovascular disease and stroke accounted for roughly 95% of total cases.

Luong *et al.* (2020) reported that during 2016 - 2017 in Ho Chi Minh City, children more likely got an acute bronchiolitis than a pneumonia, and boys were more sensitive to $PM_{2.5}$ exposure than girls. Bui *et al.* (2020) stated that the cases of diseases related to heart, respiratory, asthma, stroke observed in adults were significantly higher than in children, and respiratory diseases were dominant in hospital admissions for both children and adults. Compared the morbidity estimation based on WHO guidelines to QCVN 05/2013 in Hanoi there was a

dramatically decrease from 97% cases in 2016 to 57% cases in 2019 in the investigated diseases for children. Meanwhile, the decrease in the hospital cases of approximately 97% and 60% for adults were presented in 2016 and 2019, respectively. A similar trend on disease prevalence for children (0-14 years) and adults (>14 years) in Hanoi was reported in Ho Chi Minh City. The children group (0-14 years) suffered the most from respiratory diseases due to $PM_{2.5}$ exposure, whereas cardiovascular diseases and stroke made up above 90% of diseases for the adult group. The difference in the number of morbidities estimated from the 2 scenarios for adults in Ho Chi Minh city was in the range of 317 to 4824 cases linked to cardiovascular diseases; 4 to 28 cases related to asthma; 87 to 1351 cases associated with stroke and 23 to 358 cases linked with respiratory diseases in period of 2016 to 2019, respectively. This gap was also found in Hanoi, where ranges were of 6861 to 10700 cases, 193 to 294 cases; 3954 to 6170 cases; 380 to 1016 cases linked to heart, asthma, stroke and respiratory diseases. In summary, the number of hospital admissions increased sharply in Hanoi in comparison with Ho Chi Minh City for both age groups during 2016 to 2019 in both scenarios.

Economic loss attributed to ambient $PM_{2.5}$ exposure The economic loss of health outcomes during $PM_{2.5}$ exposure in Hanoi and Ho Chi Minh City through two scenarios (meeting WHO guideline and QCVN 05/2013 regulation) from 2016 to 2019 were estimated in this study. The total damage cost included the monetary value of reduced mortality risk (VSL), human capital loss (HCL) due to the premature death and medical treatment cost for illness (COI). When applying the scenario of WHO guideline in the period from 2016 to 2019, the total cost loss of health effects varied from 3,477,920 to 8,957,240 million of VND in Hanoi, equivalent to 0.06 – 0.15% the GDP of Vietnam. The monetary loss in Ho Chi Minh was from 1,887,853 to 2,640,176 millions VND, equivalent to 0.04 to 0.05% of the GDP of Vietnam, respectively. In the case of QCVN05/2013 scenario, the total cost ranged from 1,165,939 to 6,277,634 million VND in Hanoi, and the total cost varied from 99,043 to 564,367 million VND in Ho Chi Minh City, respectively. In other words, the average annual health-related abatement cost due to $PM_{2.5}$ exposure when $PM_{2.5}$ concentrations were controlled at WHO recommendation level was 5,072,021 and 2,375,694 millions VND in Hanoi and Ho Chi Minh,

respectively. Those values in the case of controlling PM$_{2.5}$ according to QCVN 05/2013 were 2,832,697 and 270,563 million VND in Hanoi and Ho Chi Minh City, respectively. Among costs for saving health benefits, the cost for reduction of premature mortality risks (all causes) associated with PM$_{2.5}$ exposure, contributed approximately 79-87% and 87-89% in Hanoi and Ho Chi Minh City, respectively, which was similar to previous studies (Bui *et al.,* 2020; Ding *et al.,* 2016; Huang *et al.,* 2012). Bui *et al.* (2020) calculated 98.2% of the total external cost associated with premature deaths attributed to ambient PM10 exposure from stone quarries in Ho Chi Minh city. Huang *et al.* (2012) found economic loss due to premature death and chronic respiratory disease accounted for more than 95% of the total momentary for Pearl River Delta, China. Ding *et al.* (2016) added the major health benefit from premature fatality depletion contributed to 90% of the total cost during Guangzhou Asian Games in China. When PM$_{2.5}$ level complied with QCVN 05/2013 regulation, the COI was not estimated for Ho Chi Minh City from 2016 to 2019 and Hanoi in 2017-2018 due to no hospital admission cases observed.

All economic cost was originated from premature death cases, which was mentioned above. Comparing the economic loss from health effects due to PM$_{2.5}$ exposure in the two cities, Hanoi suffered greater economic loss due to the more serious health outcomes. Our estimation was significantly lower than the estimations of Bui *et al.* (2020) of about 964,3000 billion VND in two quarries in Ho Chi Minh City, those of Huang *et al.* (2012) in Pearl River Delta of 15.51 billion Chinese Yuan (54612 billion VND, of Kim *et al.* (2019) of 7022 billion KRW (177653 billion VND) in Seoul Korean in 2014-22015. Furthermore, our result in this study was higher than that of Ding *et al.* (2016) of 165 million Chinese Yuan (584024 million VND) during Guangzhou Asian Games.

Limitations and uncertainty

The current study is one of the first one to estimate health burden and economic loss due to ambient PM$_{2.5}$ exposure in two big cities in Vietnam, which still suffered from certain limitations and uncertainties. Firstly, the assumption was that all exposed populations in studied areas were exposed to the same personal PM$_{2.5}$ concentrations, that may vary according to individual exposure characteristics and physical conditions. Secondly, the baseline mortality/incidence rate was extracted from global burden disease of Vietnam from 2016 to 2019, since data at provincial/sub-nation scale were not available for estimation. Thirdly, the exposureresponse coefficients used in the log-linear exposureresponse function were obtained from the literature review rather than local values. The exposureresponse coefficients depend on local medical condition and health condition of local population.

Therefore, it would be more reliable to apply the specific data obtained from cohort studies. Regarding economic loss estimation, except for the local medical cost, other input variables were referenced from previous studies (Ding *et al.,* 2016; Franklin *et al.,* 2007; Phung *et al.,* 2016; Pinichka *et al.,* 2017; Ren *et al.,* 2021). Furthermore, uncertainties are inevitable when using VSL derived from surveys and the benefit method transfer in the monetary evaluation of health effects.

CONCLUSION

This was one of the first study focusing on quantitative estimation of adverse health effects of PM$_{2.5}$ exposure in two big cities in Vietnam and evaluating the economic loss by health burdens in the period of 2016 - 2019. In this study, we quantified the long-term and short-term effects of ambient PM$_{2.5}$ on the risks for premature mortality associated with cardiovascular, respiratory disease, lung cancer, and hospital admissions linked to cardiovascular, respiratory disease, stroke, and asthma basing on two scenarios: WHO guideline and National Regulations on ambient air quality, QCVN05/2013. The key findings of the current study can be summarized as follow:

With the WHO baseline from 2016 to 2019, the total number of deaths linked to cardiovascular, respiratory disease and lung cancer increased from 565 to 1291 cases in Hanoi and 426 to 507 cases of death in Ho Chi Minh city in period of 2016 to 2019. Whereas with the QCVN 05/2013 baseline, the number of death cases decreased by 27 to 63% in Hanoi and by 76 to 96% in Ho Chi Minh City in 2016 and 2019, respectively. The total number of hospital admission ranged from 14387 to 37745 cases in Hanoi, from 483 to 7347 cases in Ho Chi Minh city in scenario of WHO baseline. The number of these diseases declined significantly by roughly 59% to almost 100% when applying the QCVN 05/2013 baseline.

The number of premature deaths linked to heart

diseases were higher in females while fatalities from lung cancer and respiratory disease were higher in males. The predominance of respiratory diseases was observed in children (<14 years), and cardiovascular diseases accounted for majority in disease profile in adults (>14 years).

With WHO baseline, the average annual economic loss increased, equivalent to 5,072,021 and 2,375,694 million VND in Hanoi and Ho Chi Minh, respectively. These values reduced significantly in case of QCVN05/2013, which was estimated about 2,832,697 and 270,563 million VND in Hanoi and Ho Chi Minh City, respectively.

Health burden and economic loss attributed to $PM_{2.5}$ exposures were confirmed in this study. Aggressive actions are urgent to alleviate the $PM_{2.5}$ pollution problem for public health protection. The current study provides insights in choosing effective air pollution abatement options.

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