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Research article

Model for assessing health damage from air pollution in quarrying area – Case study at Tan Uyen quarry, Ho Chi Minh megapolis, Vietnam

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ABSTRACT

Vietnam has a great demand for stone exploitation for the development of the country's infrastructure, reaching 181 million m^3 in 2020. Mining activities are always accompanied by environmental pollution, negatively affecting public health. To accurately assess the level of pollution, as well as quantify the effect of air pollution on human health, a number of structures, methods, and models provide tools to assess the benefits of this control for public health and related economic values. However, there has been no research in Vietnam applied specifically to this type of stone exploitation. This study offers a model to evaluate the economic damage caused by dust exposure from activities related to quarrying, overcoming the lack of continuous monitoring data. The area selected for research is Binh Duong province, in the Ho Chi Minh megapolis, Vietnam, which has two construction quarries, Thuong Tan and Tan My, with a current annual production of approximately 4–5 million m^3. The calculation results show that the damage to human health is estimated at approximately 9,643 billion dong a year, equivalent to 15.03 million USD. In addition, if the standard criteria are tightened, damage will continue to increase. This study also analyses some of the difficulties and limitations in the modelling process.

1. Introduction

Most countries in South and Southeast Asia, including Vietnam, have high levels of air pollution, with average annual levels often 3–10 times higher than WHO air quality standards (Yale Center for Environmental Law and Policy, 2018). Vietnam is currently ranked among the top ten air pollution in Asia, according to the annual Environmental Performance Index (EPI) report. It is worth noting that the dust concentration in biggest cities like Hanoi and Ho Chi Minh City is constantly increasing, which makes the Air Quality Index (AQI) always at an alarming level. In Hanoi, the average AQI is 121 and the PM2.5 concentration is 50.5 $\mu g/m^3$, which is double the national standard (25 $\mu g/m^3$) and five times the WHO recommendation (10 $\mu g/m^3$). In Ho Chi Minh City, the average AQI is 86, the concentration of PM2.5 is 28.3 $\mu g/m^3$, which is higher than the national standard and three times higher than the WHO standard. In addition, the average concentration of dust in the air in Ha Noi and Ho Chi Minh City is two to three times higher than the permissible level and tends to remain high. Dust pollution in large cities is mainly emitted from road emissions, construction works, roads and industries (World Bank and Institute for Health Metrics and Evaluation, 2016). Not only in large urban areas, many industrial activities, including mining, cause long-term environmental pollution and negatively affect human health (Ly et al., 2014).

As a developing country, Vietnam is in high demand for quarrying. The total demand for building stone in Vietnam reached 135 million m^3 in 2016 and is expected to increase to 181 million m^3 in 2020 (Minister, 2014) due to the demand for infrastructure construction, especially on very high-speed roads. By 2020, with 2,000 km of expressways being built and an estimated capital of US $ 48 billion, so the need to operate the stone will always be a major challenge (Minister, 2014). The case considered in this study is a quarry in Binh Duong province, in the southeastern province of Vietnam, located near the Ho Chi Minh City. The transportation of stones from the quarry to the western provinces of Vietnam, located several hundred kilometers away, is carried out mainly by the river way. At this location, fine PM10 dust is considered the main source of pollution. The source of PM10 pollution in this study is mainly mining and pretreatment such as grinding, production transport, including dust that rises from the ground. The impact of these processes on ambient air quality is discussed in an article by this research group (Ly et al., 2014). The main types of damage caused by this type of activity are

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death and illness. The causes of suicide here include respiratory and cardiovascular disease. The causes of the disease include a group of respiratory diseases (short-term): pneumonia, chronic obstructive pulmonary disease and asthma; new cases of chronic bronchitis (long-term) and groups of cardiovascular diseases (short-term): coronary heart disease, myocardial infarction and stroke; Globally, the ability to exploit quarries for infrastructure requirements has been presented in many studies (Charbonnier, 2001). Stone resources are the foundation for the creation and development of many industries, such as heavy industry and construction (Charbonnier, 2001; Fugiel et al., 2017; Boyles et al., 2017). The exploitation and its environmental impact are also diverse depending on location, structure, and type of quarries (Charbonnier, 2001). The open pits mainly contribute to the dust in the air. Dust includes debris, silica dust, coal dust, asbestos dust, and radioactive dust (Fugiel et al., 2017; Boyles et al., 2017). In the aforementioned dusts, asbestos dust and radioactive dust are very harmful to human health (Boyles et al., 2017). Dust is usually generated during blasting, excavation, loading, and transportation of minerals (Fugiel et al., 2017). In many countries around the world, there are many mining activities that affect the health of both miners and the public (Charbonnier, 2001; Fugiel et al., 2017). Quantification of damage from this type of activities is a subject of interest for many authors (Fugiel et al., 2017), assess the impact of emissions in quarries in European countries using the Life Cycle Impact Assessment (LCIA). The quarrying environmental issue have been assessed in 12 European countries (Fugiel et al., 2017). Evaluation methods, ReCiPe, and IPCC are used to quantify impacts on human health in deposits and quarries (Fugiel et al., 2017), in particular, the following quantitative assessments have been performed: greenhouse gas emissions, soil acidification, photochemical smog and dust generation, degree of harm to human health, and ecosystem quality. Many studies show that the Particulate Matters (PM) concentration increasing is harmful to human health due to exposure to the respiratory and cardiovascular systems (Lim et al., 2018; Mustafic et al., 2016; Jung et al., 2019). (Dockery, 2009) studied the effect of PM on human health, confirming that the concentration and duration of exposure to pollutants are of great importance in determining the degree of exposure. This work also shows that long-term exposure studies provide more accurate conclusions than short-term exposure studies. In the United States and Great Britain, PM pollution assessment is an essential component of the Local Air Quality Management Plan (LAQMP) (Ernst, 1993; Beattie, 2005; Dockery, 2009; Gulia et al., 2015). Many studies have also been conducted in European countries to determine the health hazards of air pollution (Hrubá et al., 2001; Jerrett et al., 2005; Macleod et al., 2006; Henschel et al., 2012; Gehring et al., 2013; Gulia et al., 2015); The authors found a positive association between an increase in fine dust concentration and the incidence of chronic respiratory diseases (e.g., chronic cough, sputum, shortness of breath, bronchitis, and bronchial asthma), some of these works have been clarified the role of air pollution in chronic respiratory diseases.

Quantitative research of air pollution damage in Vietnam is still modest. In a rare study (Ho, 2017), it also limited the amount of air pollution damage for one district (over 24 districts) of Ho Chi Minh City and only from traffic emission sources in the city. BenMAP software, based on the measurement data set, has been applied. One of the reasons why the application of BenMAP tool is difficult to apply in practice in Vietnam is that the data set to collect is difficult to achieve. Therefore, in order to quickly quantify losses in the quarrying industry, this study was performed to find suitable modeling tools. In a study conducted by the authors of this paper, based on the AERMOD modeling tool (Cimorelli et al., 2005), it is possible to clarify the extent and scope of waste sources on the 3D technology platform. Modelling results are tested with actual measurement data. However, the quantification of damage due to air pollution has not been considered in this study. The given study was designed to quantify the damage caused by PM10 pollution using data applicable in Vietnamese conditions, and uses the models studied by (Nguyen, 2013; Ding et al., 2016), and simultaneously applies two standards for PM10, first, the National Ambient Air Quality Standard (NAAQS) is 150 μg/m^3 (24 h average) (MONRE, 2013), second, for WHO is 50 μg/m^3 (average for year) (WHO, 2006).

2. Methodology

2.1. Study area

The study area is a site of stone exploitation in the Tan Uyen district of Binh Duong province, with favourable conditions for exploitation due to its remote location, far from the city, with barren and inefficient land used for agriculture (Figure 1). The stone in the area is of medium to low quality, but thanks to favourable transportation conditions, the mine is growing. The consumer market is located mainly in the Mekong Delta region, the annual production volume is currently around 4–5 million m^3. The production of quarry stone is transported by road and water transport for consumption in Ho Chi Minh City and the western provinces of Vietnam, at a distance of 100–300 km.

2.2. Model of environmental health

2.2.1. Model of health damage

A model for assessing health damage has been performed in many epidemiological studies (Altieri and Keen, 2019). The health damage function used in many studies is linear (Eq. (1)) and describes the relationship between air pollutant concentration (C) and the level of health risk by the functional relationship, Dose-Response Function (DRF). The process of determining the functional relationship between the air pollutant concentration C and dose-response (Concentration-Response Functions (CRFs)) starts with data collection; data sets must be large enough and continuous enough to run regression models, or inherited from foreign studies. The CRF function applies to average and observed 24-hour annual concentrations (Nguyen, 2013)

$$DRF = \beta \times (C - \alpha) \times POP \tag{1}$$

where, *DRF* is the impact level, calculated according to the type of damage (health endpoints); β is a coefficient of the CRFs determined from epidemiological studies (Figure 2). The coefficient β reflects the relationship between the relative risk (RR) and the change in exposure indicated by the CRFs; *C* is the concentration of air pollutant measured from the monitoring system (μg/m^3); α is the pollution threshold prescribed by law or the recommended threshold (μg/m^3); *POP* is the size of the population affected by air pollution (people exposed). The PM10 concentration was chosen to be included in the health damage model. In this study, threshold values were selected in accordance the NAAQS (MONRE, 2013) or WHO standards (WHO, 2006) to compare the results achieved (Figure 3).

2.2.2. Rapid assessment model for damage caused by air pollution

The value of economic benefits from preventing health risks is assessed by the following formula:

$$M = \sum_{i=1}^{n} DRF_i \times V_i \tag{3}$$

where, DRF_i is the degree of impact of the type of health damage *i*; V_i is the value of the economic unit of the type of health damage *i* (Vietnamese dong, VND); *M* is the total economic benefit of minimising the types of health damage (VND), in other words, the total cost of health damage from exposure to PM10 dust equal to the health damage plus damage in addition to health, such as that affecting ecology and facilities, and environmental damage (Nguyen, 2013). However, this study only considers health damage. In cases of medical examination and treatment, the cost of illness (COI) is applied. In the event of premature death, the Statistical Life Value (VSL) is used, which is the value for assessing the

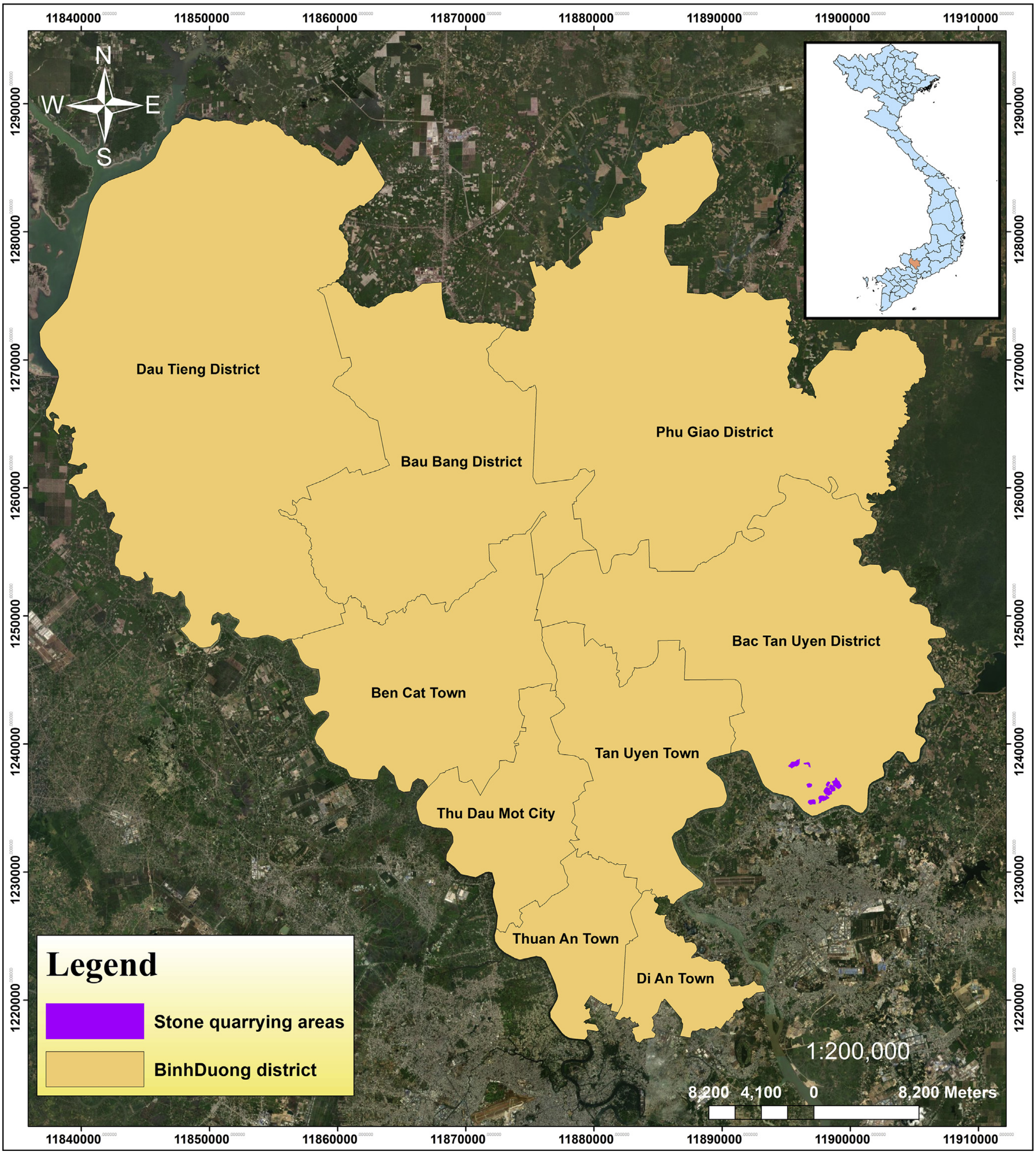


Figure 1. Location of research area: Vietnam (A); Southern region (B); Binh Duong province area (C); Thuong Tan and Tan My communities (D).

underlying risk of death (Nguyen, 2013). In fact, the labour market and wages in Vietnam do not reflect the true demand to supply, therefore, it is difficult to assess VSL through the labour market or willingness-to-pay (WTP) (Nguyen, 2013). Therefore, the study used the benefit-transfer approach (Altieri and Keen, 2019), (World Bank and Institute for Health Metrics and Evaluation, 2016) and based on OECD report (Lindhjem et al., 2011) provide specific guidelines for estimating VSL values for Vietnam in 2018. The benefit conversion method is a popular method used to estimate values from studies. Research and adjust these values to estimate the target payment value (Kim et al., 2019), (Johnson et al., 2015). In this study, the authors combined of World Bank (World Bank and Institute for Health Metrics and Evaluation, 2016), examining the cost of air pollution and VSL of the OECD group of countries as a convert value to edit. The VSL value for Vietnam in 2018 ($VSL_{Vietnam}$, 2018 (VND)) is determined by the formulas (3), (3a) and (4) below that suggest adjustments to explain the differences in income levels between national, changes in inflation and average income over time because there is a significant influence on VSL values (World Bank and Institute for Health Metrics and Evaluation, 2016). Currency conversion from USD to VND using the method of purchasing according to the Purchasing

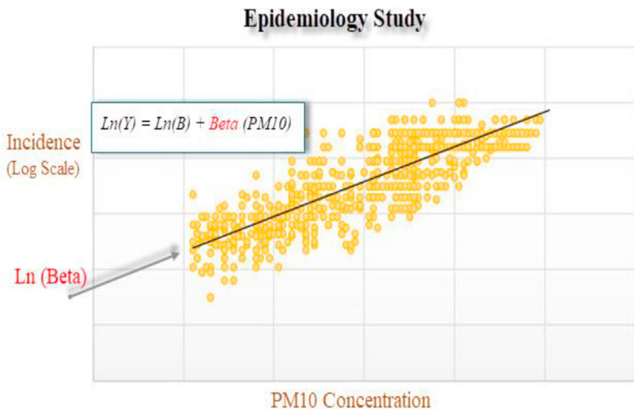


Figure 2. The coefficient β of the CRFs.

Power Parity (PPP) is also applied. Specifically, the estimated value of $VSL_{Vietnam,\ 2011\ (USD)}$ basis to determine $VSL_{Vietnam,\ 2018\ (VND)}$ is included in the rapid damage assessment model as follows:

$$VSL_{Vietnam,2011(VND)} = VSL_{OECD,2011(USD)} \times \left(\frac{Y_{Vietnam,2011}}{Y_{OECD,2011}}\right)^{e} \tag{3a}$$

where, $VSL_{Vietnam,\ 2011\ (VND)}$: is the VSL value of Vietnam in 2011, in USD units, calculated according to 2011 USD; $VSL_{OECD,\ 2011\ (USD)}$: is the average baseline VSL value estimated from sample WTP studies in OECD group of countries, in USD; $Y_{Vietnam,\ 2011}$: is the GDP per capita based on PPP, in USD units; $Y_{OECD,\ 2011}$: is the GDP per capita of the OECD group of countries based on PPP, in USD units. The coefficient *e*, used to calculate $VSL_{Vietnam,n}$, is 1.3 according to the recommendations of (World Bank and Institute for Health Metrics and Evaluation, 2016), from 1.0–1.4 to reflect the large difference in income between Vietnam and developing countries in the OECD group (Altieri and Keen, 2019); conversion rate 1 USD = 23,140 VND.

The value of $VSL_{Vietnam,\ 2011\ (USD)}$ calculated by formula (3formula (3) and (3(3a) is used as the basis for calculating Vietnam VSL_s values for the period of 2012–2018 by formula (4) (Kim et al., 2019) as follows:

$$VSL_{Vietnam,2012-2018(VND)} = \left(VSL_{Vietnam,2011(USD)} \times (1 + \%\Delta P_{2011-2018})^{e} \times (1 + \%\Delta Y_{2011-2018})^{e}\right) \times PPP_{2011-2018} \tag{4}$$

where, $VSL_{Vietnam,\ 2011\ (USD)}$: is the VSL value of Vietnam in 2011, in USD units; $\Delta P_{2011\text{-}2018}$: is the percentage of consumer price increase from 2011 to 2018 (%); $\Delta Y_{2011\text{-}2018}$: is the percentage of real GDP growth per capita from 2011 to 2018 (%); PPP_{2011}: is the exchange rate adjusted according to the purchasing power parity (PPP) in 2011 (The World Bank, 2018). Particularly for PPP conversion coefficient for the years from 2012-2018, it is based on data provided by World Bank (The World Bank Data, 2020).

2.2.3. Select the Concentration-Response Functions and mortality/morbidity rates

Air pollution caused by PM10 dust is one of the direct causes of impacts on public health both short-term and long-term; causing typical respiratory diseases is pneumonia, asthma, chronic obstructive pulmonary disease (COPD), chronic bronchitis, lung cancer (The World Bank/State Enviromenttal Proteccction Administration, 2007; Phosri et al., 2019) and cause cardiovascular diseases typically ischemic heart disease (IHD), myocardial infarction (MI), stroke, coronary-heart-disease

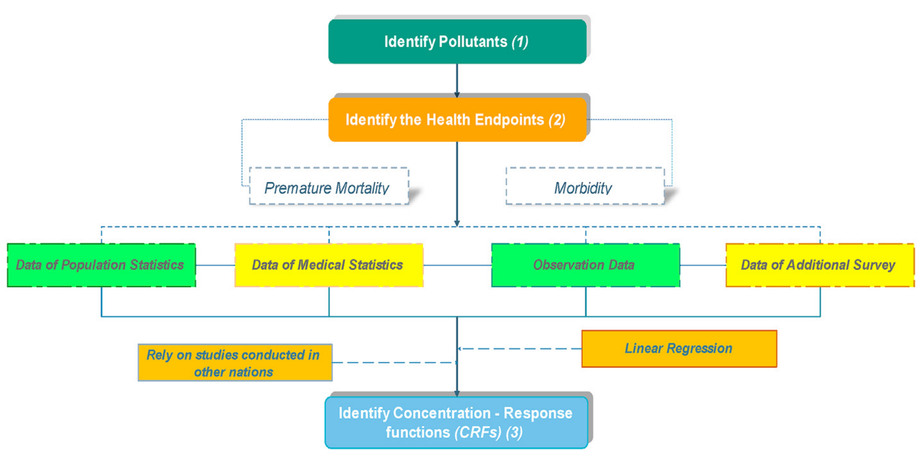


Figure 3. Procedure for determining CRFs.

Table 1. Summary of chosen health endpoint type in the model.

No.	Endpoint group	Health endpoint
1	Premature mortality	Respiratory mortality, All causes
2		Cardiovascular mortality, All causes
3	Hospital Admissions, RD[a]	All-cause respiratory diseases (excluding lung cancer diseases)
4		Pneumonia, Chronic obstructive pulmonary disease and Asthma
5	Hospital Admissions, CVD[b]	All-cause cardiovascular diseases (excluding RF[c], RHD[d])
6		Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke
7	Emergency room visit	All-cause emergency room visits
8	Chronic bronchitis	New cases of Chronic bronchitis
9	Outpatient visit	All-cause outpatient visits

Note: [a] RD: Respiratory Disease; [b] CVD: Cardiovascular Disease; [c] RF: Acute rheumatic Fever disease; [d] RHD: Chronic rheumatic Heart Disease.

Table 2. Main characteristic summary of the concentration-response functions (CRFs) using for calculation.

No.	Health endpoints	Variables	β coefficient
1	Respiratory mortality, All causes	All ages,	0.00040 (95% CI: 0.00007–0.00073)
		All gender	
2	Cardiovascular mortality, All causes	All ages,	0.00013 (95% CI: -0.00016-0.00041)
		All gender	
3	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	*Age group*	
		Children (0–14)	0.00139 (95% CI: 0.0009–0.00198)
		Adults (14–64)	0.00070 (95% CI: 0.0002–0.00129)
		Elderly (≥65)	0.00070 (95% CI: 0.0002–0.00129)
		Gender	
		Male	0.00008 (95% CI: -0.0001-0.0009)
		Female	0.00100 (95% CI: 0.0001–0.00198)
4	Hospital admissions due to Pneumonia, Chronic obstructive pulmonary disease (COPD) and Asthma	*Age group*	
		Children (0–14)	0.00123 (95% CI: 0.0007–0.00177)
		Adults (14–64)	0.00056 (95% CI: -0.0002-0.00133)
		Elderly (≥65)	0.00175 (95% CI: 0.00095–0.00256)
		Gender	
		Male	0.00135 (95% CI: 0.00085–0.00186)
		Female	0.00092 (95% CI: 0.00033–0.00152)
5	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	*Age group*	
		Children (0–14)	0.00050 (95% CI: 0.00000–0.00090)
		Adults (14–64)	0.00050 (95% CI: 0.00000–0.00090)
		Elderly (≥65)	0.00080 (95% CI: 0.00010–0.00100)
		Gender	
		Male	0.00070 (95% CI: 0.00000–0.00100)
		Female	0.00040 (95% CI: 0.00010–0.00070)
6	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	*Age group*	
		Children (0–14)	0.00103 (95% CI: 0.00068–0.00140)
		Adults (14–64)	0.00120 (95% CI: 0.00071–0.00170)
		Elderly (≥65)	0.00084 (95% CI: 0.00029–0.00383)
		Gender	
		Male	0.00115 (95% CI: 0.00066–0.00166)
		Female	0.00091 (95% CI: 0.00038–0.00143)
7	All-cause emergency room visits (respiratory and cardiovascular diseases)	All ages,	0.00001 (95% CI: -0.00009-0.00010)
		All gender	
8	New cases of Chronic bronchitis	*Age group*	
		Children (0–14)	0.00044 (95% CI: 0.00042–0.00046)
		Adults (14–64)	0.00031 (95% CI: 0.00030–0.00032)
9	All-cause outpatient visits (respiratory and cardiovascular diseases)	All ages,	0.00011 (95% CI: -0.00003-0.00026)
		All gender	

(Phosri et al., 2019) and even premature deaths. This study estimates of health damage due to PM10 exposure for deaths and morbidity through a relationship between relative risk (RR), the coefficient β of the concentration - response functions (CRFs) and pollutant concentration (C) with CRFs is a key factor to quantify the health damage caused by PM10 dust exposure (Ding et al., 2016).

In Vietnam, there is no thorough and profound epidemiological research on the dose-response relationship between air pollutants and human health. A rare study (Phung et al., 2016) performed in Ho Chi Minh City estimated the CRFs for hospitalization due to respiratory and cardiovascular diseases due to PM10 dust pollution. Full for all age groups, genders and have enough credibility. In addition, there is a study of (Le Truong and Long, 2012) performed in Ho Chi Minh City (HCMC) from 2006-2009 and (Luong et al., 2017) performed in Hanoi city in 2016; however, both of these studies were limited when estimating CRFs only taking into account the hospitalization for treatment of respiratory disease among children, not mentioning other types of damage (Health endpoints) (Nguyen, 2013). Therefore, the selection of CRFs to calculate for different local regions in Vietnam is difficult and it is necessary to inherit results from overseas studies as a basis for calculation. The types of damage (Table 1) in the study were selected based on existing data from Vietnam (Nguyen, 2013) and also based on the cost of pollution in China, based on an economic estimation of physical damage by the World Bank (WB) (World Bank and Institute for Health Metrics and Evaluation, 2016).

In this case, the coefficient β of CRFs for PM10 pollutants (Table 2) is calculated based on the relative risk value according to the relative risk model in the form of Poisson regression (Phung et al., 2016; Aunan and Pan, 2004; Cao et al., 2009) or log-linear (Guo et al., 2014; Luong et al., 2017; Phosri et al., 2019). The formula (5) is taken from the report in epidemiological studies (Table 3). The coefficient β of the CRFs is applied to all 3 target groups (from 0 - 99 years old) for children, adults and the elderly as well as by sex (male and female).

$$RR = \exp(\beta \times \Delta C) \tag{5}$$

Here, RR is the relative risk value commonly used in epidemiological studies to show the results of CRFs (Pinichka et al., 2017); the coefficient β of the CRFs, is considered as the slope factor in the log-linear relationship between the concentration of PM10 dust and the number of deaths/diseases and ΔC or C – C0: is the change in concentration from

Table 3. Summary of relative risk (RR) value selected to estimate the concentration-response function coefficient for PM10 pollutant.

No.	Variables	Types	Relative risk (RR)	References
1	**Respiratory mortality, All causes**			
	All ages, All gender	Short-term	1.004 per 10 μg/m^3, (95% CI: 1.0007–1.0073)	Guo et al. (2014)
2	**Cardiovascular mortality, All causes**			
	All ages, All gender	Short-term	1.0013 per 10 μg/m^3, (95% CI: 0.9984–1.0041)	Guo et al. (2014)
3	**Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)**			
	Age group			
	Children (0–14)	Short-term	1.0140 per 10 μg/m^3, (95% CI: 1.009–1.020)	Luong et al. (2017)
	Adults (14–64)	Short-term	1.0070 per 10 μg/m^3, (95% CI: 1.002–1.013)	Phung et al. (2016)
	Elderly (≥65)	Short-term	1.0070 per 10 μg/m^3, (95% CI: 1.002–1.013)	
	Gender			
	Male	Short-term	1.0008 per 10 μg/m^3, (95% CI: 0.999–1.009)	Phung et al. (2016)
	Female	Short-term	1.0100 per 10 μg/m^3, (95% CI: 1.001–1.020)	
4	**Hospital admissions due to Pneumonia, Chronic obstructive pulmonary disease (COPD) and Asthma**			
	Age group			
	Children (0–14)	Short-term	1.0124 per 10 μg/m^3, (95% CI: 1.007–1.0179)	Phosri et al. (2019)
	Adults (14–64)	Short-term	1.0056 per 10 μg/m^3, (95% CI: 0.998–1.0134)	
	Elderly (≥65)	Short-term	1.0177 per 10 μg/m^3, (95% CI: 1.0095–1.0259)	
	Gender			
	Male	Short-term	1.0136 per 10 μg/m^3, (95% CI: 1.0085–1.0188)	Phosri et al. (2019)
	Female	Short-term	1.0092 per 10 μg/m^3, (95% CI: 1.0033–1.0153)	
5	**Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)**			
	Age group			
	Children (0–14)	Short-term	1.005 per 10 μg/m^3, (95% CI: 1.000–1.009)	Phung et al. (2016)
	Adults (14–64)	Short-term	1.005 per 10 μg/m^3, (95% CI: 1.000–1.009)	
	Elderly (≥65)	Short-term	1.008 per 10 μg/m^3, (95% CI: 1.001–1.010)	
	Gender			
	Male	Short-term	1.007 per 10 μg/m^3, (95% CI: 1.000–1.010)	Phung et al. (2016)
	Female	Short-term	1.004 per 10 μg/m^3, (95% CI: 1.001–1.007)	
6	**Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke**			
	Age group			
	Children (0–14)	Short-term	1.0104 per 10 μg/m^3, (95% CI: 1.0068–1.0141)	Phosri et al. (2019)
	Adults (14–64)	Short-term	1.0121 per 10 μg/m^3, (95% CI: 1.0071–1.0171)	
	Elderly (≥65)	Short-term	1.0084 per 10 μg/m^3, (95% CI: 1.0029–1.039)	
	Gender			
	Male	Short-term	1.0116 per 10 μg/m^3, (95% CI: 1.0066–1.0167)	Phosri et al. (2019)
	Female	Short-term	1.0091 per 10 μg/m^3, (95% CI: 1.0038–1.0144)	
7	**All-cause emergency room visits (respiratory and cardiovascular diseases)**			
	All ages, All gender	Short-term	1.0001 per 10 μg/m^3, (95% CI: 0.9991–1.0010)	Cao et al. (2009)
8	**New cases of Chronic bronchitis**			
	Age group			
	Children (0–14)	Long-term	1.0044 per 10 μg/m^3, (95% CI: 1.0042–1.0046)	Aunan and Pan (2004)
	Adults (14–64)	Long-term	1.0031 per 10 μg/m^3, (95% CI: 1.0030–1.0032)	
9	**All-cause outpatient visits (respiratory and cardiovascular diseases)**			
	All ages, All gender	Short-term	1.0011 per 10 μg/m^3, (95% CI: 0.9997–1.0026)	Cao et al. (2009)

baseline conditions or background concentrations, based on WHO's EBD (Environmental Burden of Disease) studies (Institute for Health Metrics and Evaluation, 2015).

2.2.4. *Method choice for evaluation of cost of health damage*

The determination of the level of cost/price per unit of damage is necessary for the quantitative assessment of health damage in monetary terms. Table 4 shows the unit fee in the rapid economic damage assessment model. According to formula (3formula (3) and (3(3a) above, the calculated value of $VSL_{Vietnam,\ 2011\ (USD)}$ is about VND 1.75 billion (or USD 261 thousand according to the US $ 2011); in which: with GDP per capita based on *Purchasing Power Parity* (PPP) (Altieri and Keen, 2019), (World Bank and Institute for Health Metrics and Evaluation, 2016) according to World Bank data, 2011 as follows: $Y_{Vietnam,\ 2011}$ = 4,632.76 USD (≈31.08 million, 2011 US $) (The World Bank, 2018); $Y_{OECD,\ 2011}$ = 36,587.31 USD (≈245.47 million dong, 2011 US$) (The World Bank, 2018) and the base value of OECD $VSL_{OECD,\ 2011\ (USD)}$ default setting is 3.83 million USD according to (World Bank and Institute for Health Metrics and Evaluation, 2016) is equivalent to VND 25,696 billion (according to PPP conversion ratio (VND/USD) in 2011 (The World Bank, 2018). Vietnam VSLs values in the period of 2012–2018 are determined by formula (4) and base $VSL_{Vietnam,\ 2011\ (USD)}$ values. Vietnam's economic

Table 4. Values of health effects associated with air pollution.

No.	Health endpoints	Age groups	Value *
1	Premature mortality	Children (≤14 years of age)	2,394,480,000 VND
2		Adults (14–64 years of age) Elderly (≥65 years of age)	4,788,950,000 VND
3	Hospital Admission	Children (≤14 years of age)	17,500,000 VND
4		Adults (14–64 years of age) Elderly (≥65 years of age)	8,750,000 VND
5	Outpatient visit	Children (≤14 years of age)	3.750.000 VND
6		Adults (14–64 years of age) Elderly (≥65 years of age)	2.300.000 VND
7	Emergency room visit	Children (≤14 years of age)	750.000 VND
8		Adults (14–64 years of age) Elderly (≥65 years of age)	600.000 VND

Note: (*) The currency used in the study results is VND (Vietnam dong).

Table 5. Economic indicators of Vietnam used in calculating the Value of a Statistical Life (VSLs) in the 2012–2018 period.

$VSL_{Vietnam,\ 2011(USD)}$ = 261.000 USD	Economic indicators of Vietnam and estimated VSLs						
	2012	2013	2014	2015	2016	2017	2018
Obtained dataset from [16]							
PPP[a] conversion factor (VND/USD)	7,166.99	7,369.74	7,474.31	7,413.54	7,314.96	7,395.34	7,464.80
GDP[b] per capita annual growth (%)	4.16	4.32	4.87	5.57	5.12	5.73	6.02
CPI[c] (2011 = 100)	129.47	138.01	143.64	144.55	148.41	153.63	159.07
Estimated dataset							
%ΔY (from 2011)	0.095	0.143	0.198	0.265	0.330	0.406	0.491
%ΔP (from 2011)	0.091	0.163	0.210	0.218	0.251	0.295	0.340
$VSL_{Vietnam,\ (VND\ millions)}$	2,356.88	2,782.03	3,161.88	3,392.83	3,696.64	4,202.88	4,788.95
$VSL_{Vietnam,\ (USD\ millions)}$	0.329	0.380	0.420	0.460	0.510	0.570	0.642

Note: *[a] PPP: Purchasing-Power-Parity; [b] GDP: Gross Domestic Product; [c] CPI: Consumer Price Index.*

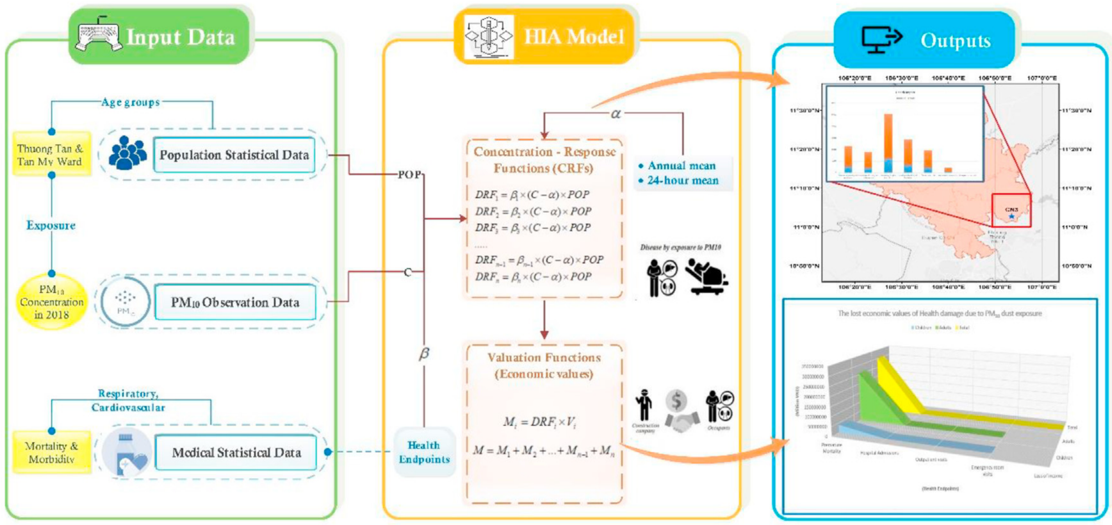
indicators for the period 2012–2018 provided from the latest updated World Bank data source to May 28, 2020 (The World Bank Data, 2020) to determine the $VSL_{Vietnam,\ 2012\text{-}2018\ values.}$ (VND). Results of selected economic indicators and VSL values of Vietnam in the years 2012–2018 are presented in Table 5 below.

Thus, for early mortality, the quantificated $VSL_{Vietnam,\ 2018\ (VND)}$ to be used for estimating loss is VND 4,778 billion, approximately US $ 642 thousand for adults and VSL for children that are half the size of adults, which is about VND 2,395 billion, approximately USD 321 thousand).

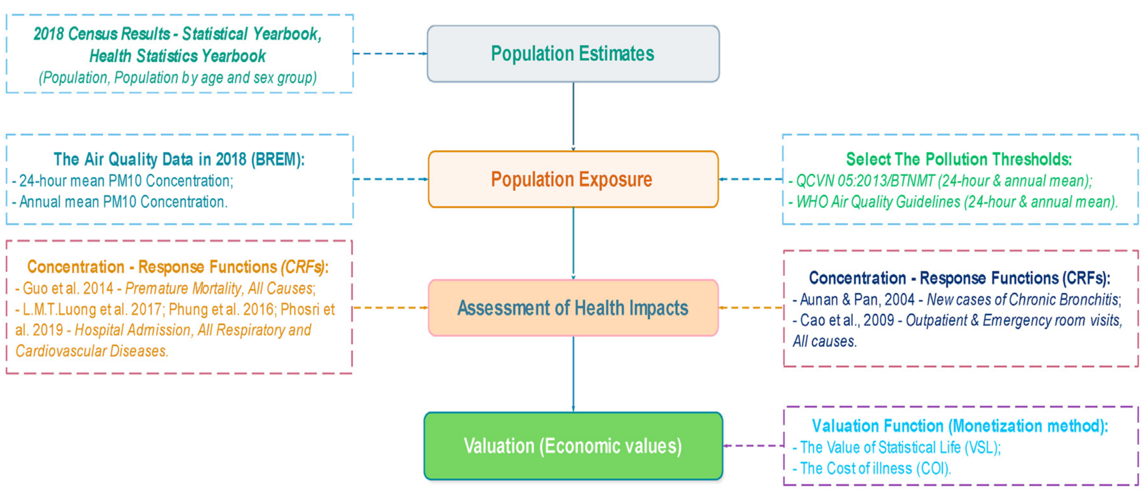
For inpatient, outpatient and emergency medical care, the cost of illness (COI) and the Human Capital (HC) valuation approach is applied (Ding et al., 2016). The COI estimates the direct cost of a treatment case, while HC estimates the lost value/product (Ding et al., 2016). In Vietnam, there are almost no accurate updated studies, so the COI value in this study is taken from (Nguyen, 2013) to evaluate the cost. Besides, the data on the average number of holidays in children: 13.2 days; In adults: 8.5 days and the ratio of hospital treatment compared to treatment at other medical facilities is 84.5% and 15.5% are also applied from the research results of (Nguyen, 2013) to calculate amount of money.

Table 6. The size of PM10 exposed population by age group and gender in the research area (Medical, 2019).

No.	Population structure	Percent to total population of province, (%)	Exposed population, (people)
Thuong Tan commune			
1	**Age groups**		
1.1	Children (0–14 years of age)	19.687	1,374
1.2	Adults (15–64 years of age)	77.168	5,384
1.3	Elderly (≥65 years of age)	3.145	219
2	**Gender**		
2.1	Male	50.277	3,508
2.2	Female	49.723	3,469
Tan My commune			
1	**Age groups**		
1.1	Children (0–14 years of age)	19.687	1,307
1.2	Adults (15–64 years of age)	77.168	5,122
1.3	Elderly (≥65 years of age)	3.145	209
2	**Gender**		
2.1	Male	50.277	3,337
2.2	Female	49.723	3,300



(A)



(B)

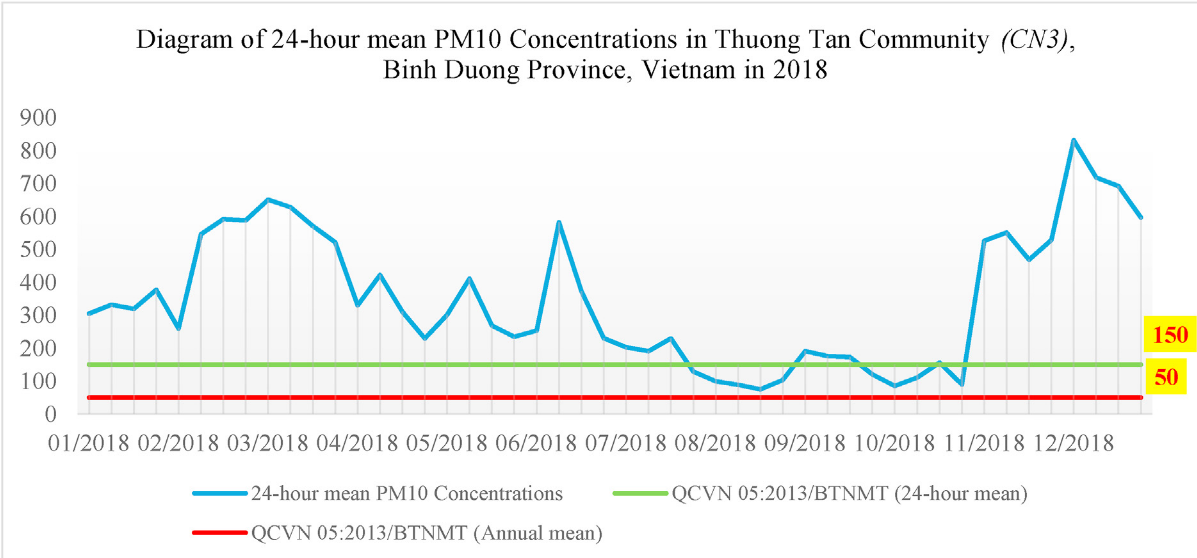
Figure 4. (A) Conceptual model; (B) Input data for health damage evaluation model and analysis of model outputs.

2.3. Observed air quality data

Data from the Binh Duong Center of Natural Resources and Environment Monitoring (BREM) on PM10 concentration, converted from total suspended particles (TSP), according to (Kan and Chen, 2004), observed during the year 2018 in the quarry area at the CN3 site (Figure 1 D) is used in this study. CN3 is one of 16 air quality monitoring locations in the province and is planned for use in the period 2016–2020; specifically, the number of monitoring months in 2018 is 12 (January 3–December 3) with a frequency of once per month and monitoring of 14 parameters at each point (Office, 2018).

2.4. Size of exposed population

The impact of air pollution in the study area is mainly due directly to quarrying activities: grinding, transporting, and stone transport. In addition, indirect factors that contribute are population density in the area and geographic space. Therefore, to determine the size of the exposed population, the number of people exposed are divided based on their age groups. According to the source (Office, 2018), the total population of the two communes in 2018 was 13,615 people, of which Thuong Tan was 6,977 people and Tan My commune was 6,637 people. Information on population structure by gender and age group of 2 communes is not included in the Health Statistics Yearbook (2016), so in the study, it is used in the structure of population structure by sex, age group in Binh Duong province (Table 6) (Medical, 2019). Specifically, the population structure of the two communes is divided into 3 groups, including 19.7% for children (≤14 years old); 77.2% for adults (15–64 years) and 3.1% for the elderly (≥65 years), the size of the total number of children exposed is 2,680 people; The exposed adults were 10,506 people and the old people exposed were 428 people, Table 6.



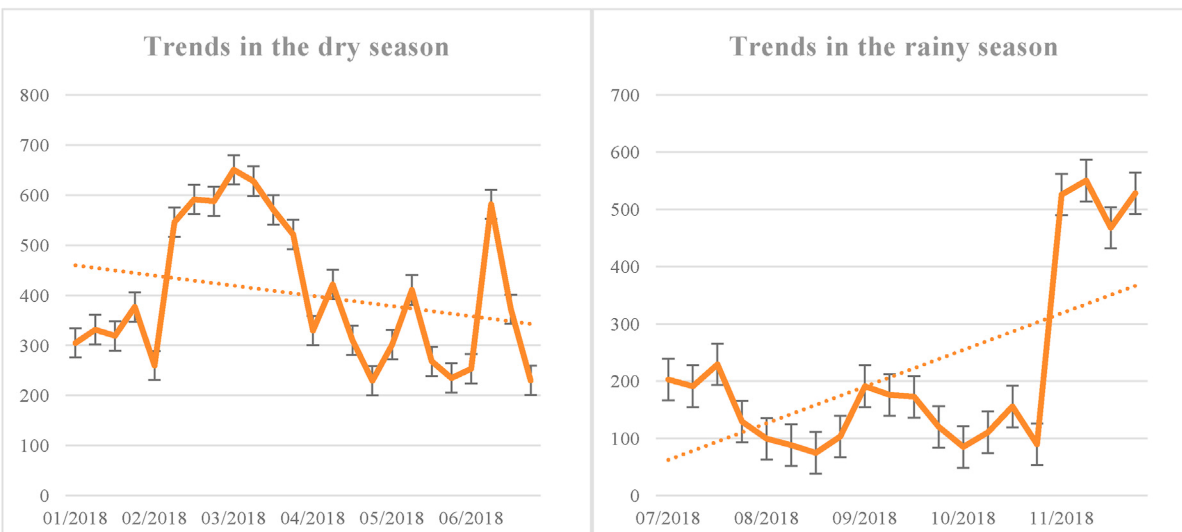


Figure 5. Evaluation of PM10 dust concentration at the monitoring location CN3, Tan Uyen quarry, Binh Duong, 2018.

3. Results and discussion

3.1. Observed air quality data with PM10

In this study, we use the monitoring results for 2018 from the local agency (Figure 4). The results show that in most of the monitoring months, the PM10 concentration in the quarrying area, converted from TSP dust according to (Kan and Chen, 2004), almost exceeded the permissible limits of NAAQS (MONRE, 2013) and only a few times, from August 2018 to early November 2018, reached the standard limit of the regulation. More specifically, in 2018, the PM10 concentration tended to increase significantly in the dry season from December 2017 to June 2018, then gradually decreased when entering the rainy season until November 2018 before showing signs of rising again. In the dry season, PM10 dust concentration ranges from 229.5 to 831.4 μg/m^3 and PM10 dust concentration in the rainy season ranges from 74.8 to 550.6 μg/m^3. The concentration of PM10 at location CN3 exceeded the permissible limit many times throughout the year, ranging from 1.04 to 5.54 times, the highest being in December 2018. The concentration of PM10 dust concentration (C) was included in the model to determine the health damage, including the average 24 h PM10 dust concentration value of 709.5 μg/m^3 and the average annual dust concentration value of 349.3 μg/m^3 (Figure 5).

3.2. Results of health damage

Population data and the average value of PM10 concentration for 2018 were included in the health damage model (1) and calculated according to the CRFs based on NAAQS (MONRE, 2013) and WHO recommendations for air quality (WHO, 2006). Tables 7 and 8 show the estimated health loss results in the two considered quarries in 2018. PM10 pollution is the main cause of most cardiovascular and respiratory diseases (Chan, 2002). The total number of deaths (all causes) was 4,030 (95% CI: -687 - 8,657); the total number of avoidable inpatient medical examination and treatment (all causes) was 10,299 (95% CI: 1,904–18, 481) and the total number of outpatient medical examination and treatment (all causes) were avoided is 837 (95% CI: -229 - 1,978) in the study area. The number of avoidable deaths from respiratory and cardiovascular diseases accounted for 20.05% and 6.52%, respectively, in all cases of health damage. If the WHO standard (WHO, 2006) is applied,

Table 7. Health impact estimation of mortality and morbidity cases (95% CI) due to PM10 dust pollution in terms of age groups (from average daily observation data of 2018).

Age groups	Health endpoints	Ranges of estimated cases, with α = 150 μg/m^3 - NAAQS standard	Ranges of estimated cases, with α = 50 μg/m^3 - WHO guidelines
Children (0 – 14)	Respiratory mortality, All causes	599 (105; 1,091)	706 (124; 1286)
	Cardiovascular mortality, All causes	195 (-240; 614)	230 (-283; 723)
	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	2,085 (1,344; 2,970)	2,457 (1,584; 3,500)
	Hospital admissions due to Pneumonia, COPD and Asthma	1,848 (1,046; 2,661)	2,178 (1,233; 3,136)
	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	748 (0; 1,344)	882 (0; 1,584)
	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	1,552 (1,016; 2,100)	1,829 (1,198; 2,475)
	All-cause emergency room visits (respiratory and cardiovascular diseases)	15 (-135; 150)	18 (-159; 177)
	New cases of Chronic bronchitis	658 (629; 688)	776 (741; 811)
	All-cause outpatient visits (respiratory and cardiovascular diseases)	165 (-45; 389)	194 (-53; 459)
Adults (15 – 64)	Respiratory mortality, All causes	2,347 (411; 4,275)	2,766 (485; 5,040)
	Cardiovascular mortality, All causes	764 (-941; 2,405)	900 (-1,109; 2,835)
	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	4,100 (1,174; 7,592)	4,833 (1,384; 8,949)
	Hospital admissions due to Pneumonia, COPD and Asthma	3,283 (-1,177; 7,824)	3,869 (-1,387; 9,223)
	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	2,932 (0; 5,267)	3,456 (0; 6,208)
	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	7,070 (4,159; 9,967)	8,333 (4,902; 11,748)
	All-cause emergency room visits (respiratory and cardiovascular diseases)	59 (-529; 588)	69 (-624; 693)
	New cases of Chronic bronchitis	1,819 (1,761; 1,878)	2,145 (2,076; 2,214)
	All-cause outpatient visits (respiratory and cardiovascular diseases)	646 (-176; 1,526)	762 (-208; 1,799)
Elderly (≥ 65)	Respiratory mortality, All causes	96 (17; 174)	113 (20; 205)
	Cardiovascular mortality, All causes	31 (-38; 98)	37 (-45; 116)
	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	167 (48; 309)	197 (56; 365)
	Hospital admissions due to Pneumonia, COPD and Asthma	420 (227; 613)	495 (267; 722)
	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	191 (24; 238)	225 (28; 281)
	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	200 (69; 917)	236 (82; 1,080)
	All-cause emergency room visits (respiratory and cardiovascular diseases)	2 (-22; 24)	3 (-25; 28)
	New cases of Chronic bronchitis	-	-
	All-cause outpatient visits (respiratory and cardiovascular diseases)	26 (-7; 62)	31 (-8; 73)

the number of deaths, inpatient and outpatient treatment and minimized treatment is even higher, at 4,751 (95% CI: -809 - 10,204).; 12,140 (95% CI: 2,244–21,785) and 987 (95% CI: -269 - 2,331).

For Thuong Tan commune, the number of premature deaths due to respiratory diseases among children and adults decreased significantly when controlling the average PM10 dust concentration of 24-h reaching NAAQS (MONRE, 2013), respectively are 307 (95% CI: 54–559) and 1, 202 (95% CI: 211–2,191). The same thing was found with early deaths from cardiovascular diseases, namely 100 (95% CI: -123 - 314) in children and 391 (95% CI: -482 - 1,232) in the adult group. The elderly group (≥65) of premature deaths tended to decrease, only 49 (95% CI: 9–89) due to respiratory diseases and 16 (95% CI: -20 - 50) due to Cardiovascular disease. The number of hospitalizations for treatment of respiratory diseases (except for lung cancer) among children decreased by 1,068 (95% CI: 689–1,522), especially for Pneumonia, COPD and Asthma diseases decreased by 947 (95% CI: 536–1,363) and the same for adults reduced by 2,101 (95% CI: 602–3,891) hospitalizations for treatment of respiratory illnesses. At the same time, in the 3 groups of children, adults and the elderly also had a sharp decrease in hospitalizations for IHD, MI and Stroke, respectively, 795 (95% CI: 521–1,076); 3,623 (95% CI: 2, 131–5,107) and 103 (95% CI: 36–470). For Tan My commune, the number of premature deaths and avoidable diseases is about 1.05 times lower than that of Thuong Tan commune. The number of premature deaths from respiratory diseases decreased by 292 (95% CI: 51–532) in children; 1,144 (95% CI: 201–2,084) in adults; 47 (95% CI: 8–85) in the elderly and the number of deaths from cardiovascular diseases decreased 95 (95% CI: -117 - 299) in children; 372 (95% CI: -459 - 1,172) in adults; 15 (95% CI: -19 - 48) in the elderly. The number of hospitalizations for treatment of respiratory diseases (except lung cancer) and cardiovascular diseases (except for RF, RHD) also decreased significantly in the age group <64 years, specifically for respiratory diseases decreased by 1,016 (95% CI: 655–1,448) in children; 1,999 (95% CI: 573–3,701) in adults and for cardiovascular diseases decreased 365 (95% CI: 0–655) in children; 1,429 (95% CI: 0–2,567) in adults.

With the reduction of the average annual PM10 dust concentration reaching NAAQS (MONRE, 2013), the total number of premature deaths (all causes) will be 2,156 (95% CI: -367 - 4,631); the total number of inpatient medical examination and treatment (all causes) was 5,510 (95% CI: 1,019–9,887) and the total number of outpatient medical examination and treatment (all causes) avoidable is 448 (95% CI: -122 - 1, 058) in the study area. Similarly, if the WHO standard is applied, the number of premature deaths, inpatient and outpatient care and treatment will be higher, at 2,372 (95% CI: -404 - 5,095); 6,062 (95% CI: 1,121–10, 878) and 493 (95% CI: -135 - 1,164). For Thuong Tan commune, when the average annual concentration of PM10 dust in the controlled area reaches the limit of NAAQS (MONRE, 2013), the number of premature deaths from respiratory and cardiovascular diseases is reduced to 218. (95% CI: -37 - 467) in children; 853 (95% CI: -145 - 1,831) in adults and 35 (95% CI: -6 - 75) in the elderly. The number of visits to and treat respiratory diseases (except lung cancer) among children and adults also decreased significantly, respectively 621 (95% CI: 319–962); 1,317 (95% CI: 129–2,661) and this is similar for the number of visits to and treatment of cardiovascular diseases (except RF, RHD) respectively 254 (95% CI: -49 - 516) in children you; 997 (95% CI: -193 - 2.023) in adults. In the case of Tan My commune, the estimated number of premature deaths reduced due to respiratory and cardiovascular diseases among children, adults and the elderly was 207 (95% CI: -35 - 444); 811 (95% CI: -138 - 1, 742) and 33 (95% CI: -6 - 71). The number of visits to, hospitalized for

Table 8. Health impact estimation of mortality and morbidity cases (95% CI) due to PM10 dust pollution in terms of age groups (from average annual observation data of 2018).

Age groups	Health endpoints	Ranges of estimated cases, with α = 50 μg/m^3 - NAAQS standard	Ranges of estimated cases, with α = 20 μg/m^3 - WHO guidelines
Children (0–14)	Respiratory mortality, All causes	320 (56; 583)	352 (62; 642)
	Cardiovascular mortality, All causes	104 (-128; 328)	115 (-141; 361)
	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	1,115 (719; 1,589)	1,227 (791; 1,748)
	Hospital admissions due to Pneumonia, COPD and Asthma	989 (560; 1,423)	1,088 (616; 1,566)
	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	400 (0; 719)	440 (0; 791)
	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	830 (544; 1,123)	913 (598; 1,236)
	All-cause emergency room visits (respiratory and cardiovascular diseases)	8 (-72; 80)	9 (-79; 88)
	New cases of Chronic bronchitis	352 (336; 368)	388 (370; 405)
	All-cause outpatient visits (respiratory and cardiovascular diseases)	88 (-24; 208)	97 (-26; 229)
Adults (15–64)	Respiratory mortality, All causes	1,255 (220; 2,287)	1,381 (242; 2,516)
	Cardiovascular mortality, All causes	409 (-504; 1,287)	449 (-554; 1,416)
	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	2,194 (628; 4,062)	2,413 (691; 4,469)
	Hospital admissions due to Pneumonia, COPD and Asthma	1,756 (-630; 4,186)	1,932 (-693; 4,605)
	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	1,568 (0; 2,817)	1,726 (0; 3,100)
	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	3,782 (2,225; 5,332)	4,161 (2,448; 5,866)
	All-cause emergency room visits (respiratory and cardiovascular diseases)	31 (-283; 314)	35 (-312; 346)
	New cases of Chronic bronchitis	973 (942; 1,005)	1,071 (1,036; 1,105)
	All-cause outpatient visits (respiratory and cardiovascular diseases)	346 (-94; 817)	380 (-104; 898)
Elderly (≥65)	Respiratory mortality, All causes	51 (9; 93)	56 (10; 103)
	Cardiovascular mortality, All causes	17 (-21; 52)	18 (-23; 58)
	Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	89 (26; 166)	98 (28; 182)
	Hospital admissions due to Pneumonia, COPD and Asthma	225 (121; 328)	247 (133; 361)
	Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	102 (13; 128)	112 (14; 140)
	Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	107 (37; 490)	118 (41; 539)
	All-cause emergency room visits (respiratory and cardiovascular diseases)	1 (-12; 13)	1 (-13; 14)
	New cases of Chronic bronchitis	-	-
	All-cause outpatient visits (respiratory and cardiovascular diseases)	14 (-4; 33)	16 (-4; 37)

treatment of respiratory and cardiovascular diseases in Tan My commune is reduced to 786 (95% CI: 303–1,265) in children; 2,018 (95% CI: 122–3,905) in adults and 101 (95% CI: 11–165) in the elderly.

At the same time, the study results also showed that when the control of PM10 concentration reached NAAQS (MONRE, 2013), average 24-h, the number of new chronic (long-term) bronchitis cases in 2 communes of Thuong Tan and Tan My will decrease. 658 (95% CI: 629–688) in children and 1,819 (95% CI: 1,761–1,878) in adults. Similarly, when controlling the average PM10 dust concentration to reach NAAQS (MONRE, 2013), annual average, the number of minimized cases in these 2 groups is 352 (95% CI: 336–368) and 973 (95% CI).: 942–1, 005).

Table 9. Health impact estimation of mortality and morbidity cases (95% CI) due to PM10 dust pollution in terms of gender (according to NAAQS standard).

Health endpoints	Gender	Ranges of estimated cases, with α = 150 μg/m^3 – Average daily limit	Ranges of estimated cases, with α = 150 μg/m^3 – Average annual limit
Respiratory mortality, All causes	Male	1,529 (268; 2,786)	818 (143; 1,490)
	Female	1,512 (265; 2,755)	809 (142; 1,474)
Cardiovascular mortality, All causes	Male	498 (-613; 1,567)	266 (-328; 838)
	Female	492 (-606; 1,550)	263 (-324; 829)
Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	Male	306 (-383; 3,431)	164 (-205; 1,836)
	Female	3,769 (379; 7,500)	2,016 (203; 4,012)
Hospital admissions due to Pneumonia, COPD and Asthma	Male	5,173 (3,242; 7,133)	2,768 (1,734; 3,816)
	Female	3,469 (1,348; 5,751)	1,856 (668; 3,077)
Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	Male	2,671 (0; 3,811)	1,429 (0; 2,039)
	Female	1,512 (379; 2,642)	809 (203; 1,413)
Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	Male	4,417 (2,519; 6,343)	2,363 (1,348; 3,393)
	Female	3,431 (1,437; 5,415)	1,835 (768; 2,897)
All-cause emergency room visits (respiratory and cardiovascular diseases)	Male	38 (-345; 383)	20 (-184; 205)
	Female	38 (-341; 379)	20 (-182; 203)
All-cause outpatient visits (respiratory and cardiovascular diseases)	Male	421 (-115; 994)	225 (-61; 532)
	Female	416 (-114; 983)	223 (-61; 526)

Table 10. Health impact estimation of mortality and morbidity cases (95% CI) due to PM10 dust pollution in terms of gender (according to WHO guidelines).

Health endpoints	Gender	Ranges of estimated cases, with $\alpha = 50$ μg/m^3 – Average daily limit	Ranges of estimated cases, with $\alpha = 20$ μg/m^3 – Average annual limit
Respiratory mortality, All causes	Male	1,802 (316; 3,283)	900 (158; 1,640)
	Female	1,782 (312; 3,247)	890 (156; 1,621)
Cardiovascular mortality, All causes	Male	586 (-723; 1,847)	293 (-361; 922)
	Female	580 (-715; 1,827)	290 (-357; 912)
Hospital admissions due to all-cause respiratory diseases (excluding lung cancer diseases)	Male	361 (-452; 4,045)	180 (-226; 2,020)
	Female	4,442 (446; 8,841)	2,218 (223; 4,415)
Hospital admissions due to Pneumonia, COPD and Asthma	Male	6,098 (3,821; 8,408)	3,045 (1,908; 4,198)
	Female	4,089 (1,471; 6,779)	2,042 (734; 3,385)
Hospital admissions due to all-cause cardiovascular diseases (excluding RF, RHD)	Male	3,149 (0; 4,492)	1,572 (0; 2,243)
	Female	1,782 (446; 3,114)	890 (223; 1,555)
Hospital admissions due to Ischemic Heart Disease (IHD), Myocardial Infarction (MI) and Stroke	Male	5,206 (2,970; 7,477)	2600 (1,483; 3,733)
	Female	4,044 (1,693; 6,383)	2,019 (846; 3,187)
All-cause emergency room visits (respiratory and cardiovascular diseases)	Male	45 (-406; 451)	23 (-203; 225)
	Female	45 (-402; 446)	22 (-201; 223)
All-cause outpatient visits (respiratory and cardiovascular diseases)	Male	496 (-135; 1,172)	248 (-68; 585)
	Female	491 (-134; 1,159)	245 (-67; 579)

In addition, when considering gender based on research results, it can be seen that the number of premature deaths and avoidable morbidity in men is higher than women in Thuong Tan and Tan My communes when PM10 dust concentration control is limited (except for inpatient hospitalization for respiratory diseases) (Table 9). Specifically, for the control of PM10 dust concentration averaged 24-h reaching NAAQS, the number of premature deaths from respiratory and cardiovascular diseases is reduced to 2,026 (95% CI: -345 - 4,353) in men; 2004 (95% CI: -341 - 4,305) in women and the reduction in the number of visits and hospitalizations for respiratory and cardiovascular diseases in these two groups was 3,437 (95% CI: -843). - 8,619) and 5,735 (95% CI: 302–11,504). In the case of the annual average control of PM10 dust concentration of Vietnam standard, the number of premature deaths from cardiovascular and respiratory diseases is 1,084 (95% CI: -185 - 2,328) in men; 1072 (95% CI: -183 - 2.303) and similar for the number of hospitalizations for treatment of illnesses for these two groups of subjects are 1,839 (95% CI: -451 - 4,611) and 3,068 (95% CI: 162–6,154).

The results also show that, when applying the WHO (WHO, 2006) standard to control PM10 dust pollution, the number of premature deaths and avoidable diseases will be higher than the application of NAAQS (MONRE, 2013) (Table 10).

3.3. The result of the cost of health damage

The cash cost model transformed health loss into a monetary value using VSL along with COI assumptions to estimate the economic loss as a result of PM10 dust exposure. Table 7 presents the results of a rapid health damage assessment for the two stone quarries: Thuong Tan and Tan My, Binh Duong province. The health benefits that contributed to cost saving were mainly associated with a reduction in the risk of premature death (all causes), contribute 98.24% of total benefits. The results of the rapid assessment show that the relative risk reduction for premature deaths (both children, adults and the elderly) cases meets NAAQS, 50 μg/m^3 is 9,476 billion dong/year (equivalent to about 14.8 million USD) and in case of meeting the WHO standard (20 μg/m^3) is 10,426 billion VND/year (equivalent to about 16.3 million USD). The amount of money needed to avoid disease risks for all 3 groups corresponding to NAAQS and WHO Standards are respectively VND 145 billion (approximately USD 226.02 thousand) and VND 160 billion (equivalent to about 249.4 thousand USD). In addition, the economic benefits that met NAAQS and WHO Standards were valued at VND 22 billion (US $ 34.29 thousand) and VND 24 billion (US $ 37.41 thousand) (see Table 11).

Table 11. The damage monetary value of health impact due to PM10 dust pollution in 2018 (estimating from observation data).

Age groups	Health endpoints	Cost of pollution (VND millions), associated with meeting NAAQS	Cost of pollution (VND millions), associated with meeting WHO guidelines
Children	All-cause premature mortality	1,016,000	1,118,000
	Hospital admissions due to RD and CVD (short-term)	58,300	64,200
	Outpatient visit due to RD and CVD	300	400
	All-cause emergency room visits	6	7
	Lost income due to time off work (take care of sick children)	7,153	7,870
Adults	All-cause premature mortality	7,968,100	8,766,800
	Hospital admissions due to RD and CVD (short-term)	81,400	89,500
	Outpatient visit due to RD and CVD	800	900
	All-cause emergency room visits	19	21
	Lost income due to time off work	12,800	14,100
	Reduced labor productivity	1,285	1,414
Elderly	All-cause premature mortality	324,700	357,300
	Hospital admissions due to RD and CVD (short-term)	4,600	5,040
	Outpatient visit due to RD and CVD	32	36
	All-cause emergency room visits	1	1
	Lost income due to time off work (take care of sick elderly)	700	800

4. Discussion

4.1. Uncertainty analysis

Model inputs in this study include data on air quality are population exposure (population of Thuong Tan and Tan My communities), CRF, and β coefficient, as well as monetary values. Each type of model input can, to varying degrees, affect the final calculation results. Therefore, the accuracy and reliability of the results should be carefully assessed. The results of the estimated population size were taken from reliable local data sources: the Binh Duong Statistical Yearbook 2018 (Office, 2018) and the 2016 Health Statistics Yearbook (Medical, 2019). Therefore, the result of the damage assessment mainly depends on the choice of CRF, coefficient β. Very few quantitative and incomplete studies of the relationship between air pollution and health have been conducted in Vietnam, especially epidemiological studies of the relationship between PM10 dust concentration and the health effects of urban dwellers. Therefore, except for the cost of inpatient hospitalization, this study uses a set of coefficients β and CRFs from similar studies in Thailand (Phosri et al., 2019; Pinichka et al., 2017) and China (Aunan and Pan, 2004; Cao et al., 2009) for other types of health damage.

4.2. Value of economic benefits

In some developing countries like Vietnam, PM10 pollution is really a serious problem, causing significant economic losses due to the impacts on ecosystems, vision limits to social issues such as reduced productivity or sick leave, and even death. In this study, we initially consider the economic values of damage due to air pollution from quarrying caused by deaths and illnesses; although the greatest economic loss (or gain) is primarily due to early deaths (Berman et al., 2012; Fann et al., 2011). Quantifying the impact of PM10 pollution on the study area on the basis of NAAQS and WHO international standards, including focusing on quantifying the value of damage caused by premature death through VSL value. The most common approach used to evaluate health values is based on the principle of willingness to pay and willingness to accept, whereby each individual will state the amount of money they accept given to conduct a replacement. change the current environmental status to reduce health risks (WTP) or will accept risks and pay to overcome them so as not to affect their current benefits (WTA) (Nguyen, 2013). Ideally, therefore, the implementation of an individual WTP survey in the study area to estimate VSL, however this was not done in this study, so the benefit conversion method was applied. to adjust VSL values for Vietnamese conditions; This method has been used in many reliable international studies (Altieri and Keen, 2019; Kim et al., 2019; Robinson et al., 2019). At the same time, the sensitivity range of the income difference coefficient from 1 - 1.4 as recommended by (World Bank and Institute for Health Metrics and Evaluation, 2016) for developing countries is also applied in the calculation with selection difference $e = 1.3$. According to (Department of Statistics Ho Chi Minh City, 2019), by the year of 2018, the GRDP scale of Binh Duong province reached VND 322.98 trillion, with the results of quantifying the economic damage caused by air pollution according to NAAQS of VND 9,643 billion will account for about 2.98% of GRDP and according to the WHO Standard of VND 10,610 billion will account for about 3.29% of GRDP or in other words, the control of PM10 in the area that reaches the allowable limit will contribute. It is estimated that the GRDP for Binh Duong province is around 2–3%.

5. Conclusions

(1) The study proposed a rapid assessment model due to air pollution damage, using PM10 criteria for the type of quarrying in Vietnam. The assessment results show that in 2018, air pollution, particularly PM10, caused health damage to the people in the study area. A linear health damage estimation model has been applied, showing the relationship between the level of health risks, the concentration of contaminants and costs. From the limitations of the rapid damage quantification model, which only considers health damage, additional costs were calculated for early visits, medical treatment and death. Based on standard data from the statistical yearbook to estimate the health damage due to air pollution, the result of quantifying the economic value of damage according to NAAQS in the study area is approximately 9,643 billion VND/year, equivalent to about 15.03 million USD.

(2) The results also show that, if the required standard is tightened, the value of the damage will increase, namely the damage will be about 10,610 billion VND/year, equivalent to about 16.54 million USD when calculated according to WHO standards. In the context that Vietnam has a great demand for quarrying, this study will help policy makers see the impact on people's health and have appropriate compensation policies.

(3) The results of the study show that premature deaths accounted for a significant proportion of 98.24% and that the adult population (men) is always the most affected, which is a matter of forcing local authorities and units. Employers must urgently implement synchronous policies to minimize impacts.

(4) The research results show that the first priority should be workers working in quarry mines, the labor protection monitoring network system must be strengthened, fully equipped with protection. It is necessary to equip adequate specialized labor protection devices for each job position, organize periodic health examinations and prepare health management records for workers. Children and the elderly are the next sensitive objects affected by PM10 exposure in the region, so organizational and technical measures must be taken by the quarrying units strictly under the supervision of management levels.

Declarations

Author contribution statement

Long Ta Bui: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Phong Hoang Nguyen: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Duyen My Chau Nguyen: Performed the experiments; Analyzed and interpreted the data.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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